FAIRCHILD SPACE

ADVANCED PROTEIN CRYSTAL GROWTH PROGRAMMATIC SENSITIVITY STUDY FINAL REPORT

JULY 1992

NASA CONTRACT NAS8-39352

Huntsville Technical Support Center
1525 Perimeter Parkway, Suite 200
Huntsville, Alabama 35806

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1.0 INTRODUCTION

This is the final report for contract NAS8-39352 - Advanced Protein Crystal Growth Programmatic Sensitivity Study, conducted under the cognizance of the Microgravity Experiment Projects Office of the Payload Projects Office at the Marshall Space Flight Center. The period of performance for this contract was from December 16, l991 through July 24, l992. A status report was published mid-May 1992 covering Task 1 "Crystal Growth Method Baseline Development"; and except for minor changes necessary to insure continuity, it forms an integral part of this final report. The other three Tasks, "Crystal Growth Program Development", "Crystal Growth Program Sensitivity Impact Determination" and, "Preparation of Reports" are also reported in detail herein.

The purpose of this study is to define the costs of various APCG (Advanced Protein Crystal Growth) program options and to determine the parameters which, if changed, impact the costs and goals of the programs and to what extent. This was accomplished by developing and evaluating several alternate programmatic scenarios for the microgravity Advanced Protein Crystal Growth program transitioning from the present shuttle activity to the man tended Space Station to the permanently manned Space Station. These scenarios include selected variations in such sensitivity parameters as development and operational costs, schedules, technology issues, and crystal growth methods. This final report provides information that will aid in planning the Advanced Protein Crystal Growth Program.

2.0 LITERATURE SEARCH

Step one in the study approach was an extensive literature search. This enabled us to determine and document a definition of the three selected protein crystal growth methods: 1. vapor diffusion, 2. liquid diffusion, and 3. dynamically controlled crystallization. These three methods were selected by the NASA TM at the beginning of the contract.

The Science Capabilities Document (SCD), dated January 1992 [18] presents a synopsis for an advanced protein crystal growth program and defines the proposed major program objectives and goals. The information contained in this document was used in forming the foundation of what-to-look-for in our initial approach to the literature search. References 1 and 2, *Preparation and Analysis of Protein Crystals,* McPherson, 1982; and *Protein Crystallography,* Blundell and Johnson, 1976 were also used in developing the literature search guidelines.

Data has been collected through personal search and/or remote on-line computer access to The Redstone Scientific Information Center(RSIC), personal contact with the MSFC Central Technical Library, MSFC Central Repository, and UAH Library. Several data base searches, including NASA/RECON, and Defense Technology Information Center (DTIC) were made for us by RSIC. Figure 2.0-1 represents a numerical summary of the following literature search and author identification portion of Task 1. These cumulative searches yielded over 250 abstracts from various journals and symposia. Each of these abstracts

- 252 JOURNAL AND SYMPOSIA ABSTRACTS REVIEWED
- 83 SELECTED ARTICLES EXAMINED
- 43 BOOKS AND TECHNICAL MEMORANDA EXAMINED
- 156 INVESTIGATORS AND AUTHORS

	UNITED STATES	FOREIGN
GOVERNMENT	26	10
UNIVERSITIES	53	16
INDUSTRY	36	15
TOTAL	115	41

Figure 2.0-1 Literature Survey Summary

was reviewed and over 80 documents selected for procurement and careful examination. The majority of the selected articles were available locally on microfiche and copies were obtained during the first two weeks of the study. The remaining articles were ordered and arrived within the next two-three weeks. More than 40 books and technical memoranda were also examined for appropriate information. A total of more than 150 authors were identified, representing 115 US and 41 foreign organizations from Government, Universities and Industry. A more detailed breakdown of the representation is also shown on Figure 2.0-1 Appendix F is a detailed list of these authors by organization; address and phone number is also given where possible.

The method and mode of operation identification and definition began as the requisitioned articles and books came in. There were approximately fifteen different methods of growing crystals initially identified in the documents reviewed; they are listed in Figure 2.0-2. Two to three potential crystal growth investigator contacts for each of the three selected methods and one or two contacts for some of the other methods were identified.

- 0 Vapor Diffusion
  - Hanging Drop
  - Sitting Drop
- 0 Liquid-Liquid Diffusion
  - Boundary Layer
  - Interface
  - Dialysis
- 0 Containerless
- 0 Dynamic Control
- 0 Batch
- 0 Gel
- 0 Melt
- 0 Bulk
- 0 Temp Induced
- 0 pH Induced

Figure 2.0-2 Crystal Growth Method

A two part general conclusion became apparent early in the literature review cycle. First, for the purposes of this study, there are basically two protein crystal growth methods: vapor diffusion and liquid diffusion. Second, the term "dynamic control", to be properly evaluated in this study, will be defined as the overall technique of adjusting experiment conditions, either preplanned or real-time. This conclusion was reinforced as more documents were reviewed and personal contacts made. Rationale for this conclusion is summarized as follows.

Crystal growth method: The definition data obtained from the literature are very broad, and sometimes synonymous descriptions are used in terms of methods / techniques / systems for accomplishing crystal growth in microgravity. For instance, the term "hanging drop" was frequently used interchangeably with "vapor diffusion" as the description [7] of the method under discussion. At other times the terms "hanging drop" and "sitting drop" were used to describe techniques within the vapor diffusion method. There are various techniques [9] to create the optimal environment for a crystal growing in the solution: vapor diffusion (hanging drop or sitting drop); dialysis technique; liquid-liquid diffusion (salting-in/salting-out technique); and temperature gradient technique. Any of these techniques can be adapted for protein crystal growth under microgravity conditions [3].

The first U.S. protein crystal growth experiment in space [3] was flown on Shuttle Mission 41-D in August, 1984. This MDAC/ Scripps joint effort experiment, and the Spacelab I experiments by Littke and John [6] involved the liquid-liquid diffusion method. The experiment was unsuccessful for the most part due to unexpected micro gravity effects causing the salt solution to migrate prematurely into the valve block where it dried and blocked the mixing action of the syringes.

One of the most widely used methods of crystallizing proteins involves the slow precipitation of protein from droplets of solution by vapor pressure equilibration (vapor diffusion) against a solution containing a higher concentration of the precipitating agent; the "hanging-drop method" is a common version [7] of this general technique. Microdialysis [10] has been selected by some prominent experimenters as their second priority recommendation for development for space experiments. The vapor diffusion and/or dialysis experiments on all shuttle flights (except STS-61C) yielded significantly larger crystals than those obtained from ground-based experiments.

Three different crystallization methodologies [4] were used successfully on board the Russian MIR Space Station: batch, vapor diffusion, and boundary layer diffusion - both batch and boundary layer were used concurrently in the same apparatus.

Space shuttle experiments have been invaluable [8] in optimizing some major variables and determining hardware design. However, future designs should include monitoring and/or dynamic control [5] of temperature as well as other critical variables for further optimization and for comparison to earth-grown crystals.

The parametric data e.g., functions and capabilities needed for our evaluation, were usually expressed as overall requirements regardless of the method or technique used to obtain the crystals. Programmatic sensitivity evaluation of these methods and various accompanying parameters, was structured to accommodate the broad descriptions found in the literature. More specific method definitions were generated and documented as necessary (Section 7.0) based on our experience and best engineering judgement.

Dynamic control: The term dynamic control is defined as being able to change the conditions under which the crystal growth is occurring, such as, temperature, protein concentrations, etc. so that the growth process can be actively controlled. This could be accomplished in "real time" by the crew or by ground control or by a preplanned program using a computer. It is felt that dynamic control is considered a technique generally applicable, to one degree or another, to all methods. New methods that will permit dynamic monitoring and control [5,8] of nucleation and various other parameters are being developed. To help clarify this concept of dynamic control, the term "static control" was coined to represent the case where either there are no changes made in growth conditions or there are only those changes made via preplanned control operations. As shown on Figure 2.0-3, all of the methods of growing crystal can be operated either by dynamic control or static control. It is recognized that there are many other identified techniques for growing protein crystals, and many factors which effect the outcome of particular experiments; but, for the purposes of this programmatic sensitivity study, these two simplifying classifications are recommended. These recommendations are not intended to over simplify the very complex science of growing crystals, but are presented as the best means of accommodating the study approach.

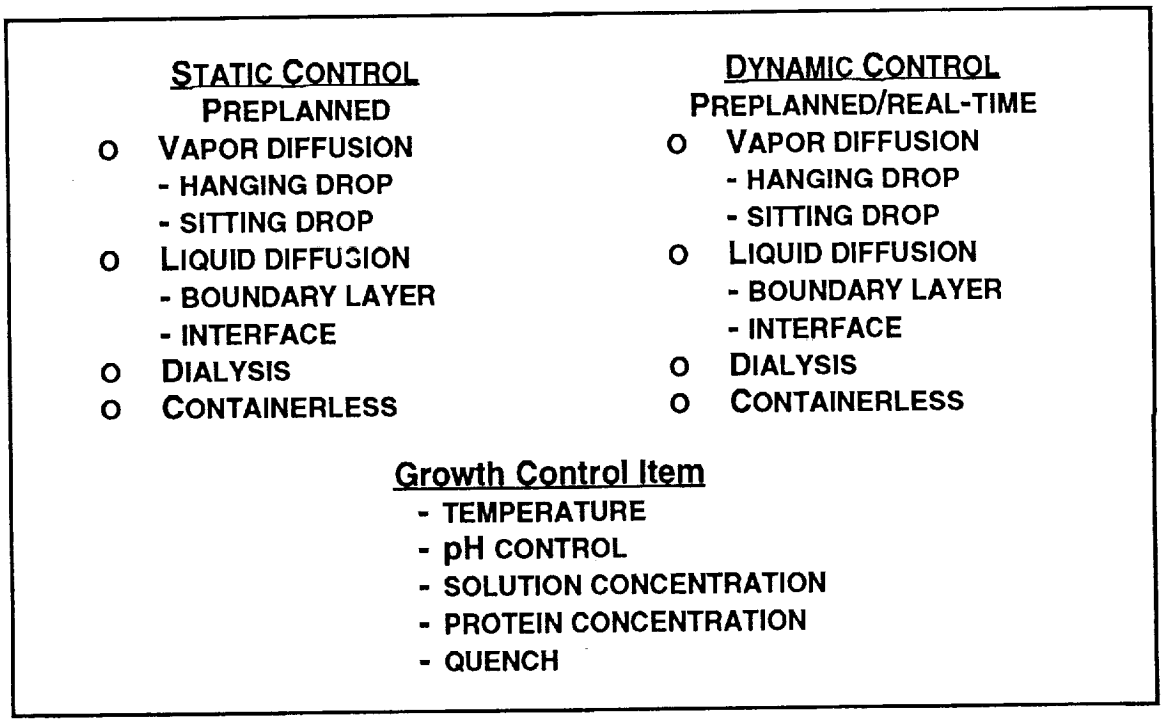


Figure 2.0-3 Crystal Growth Methods Classification

Based on the frequency of use for these "interchangeable" method / technique descriptions, indicating a general acceptance and understanding of these terms in the scientific community, and discussions with NASA personnel, the decision was made to use the vapor diffusion, liquid diffusion and dynamic control / static control crystal growth method and mode of operation designations described above for the remainder of the study.

It was initially anticipated that the information needed to adequately define a crystal growth method for cost and programmatic impact evaluation would be required at the experiment hardware or apparatus level. It would include, but not be limited to, it's name, (and/or subname as necessary) , physical description (weight, volume, dimensions,etc.), modes of operation, requirements [power, control, etc.], and accompanying costs. The available literature was carefully reviewed for this descriptive data to define the baseline methods. The method definitions generated during the literature search are based on descriptions of existing experiment hardware items, e.g., apparatuses, and thermal enclosures, that are presently being flown on the shuttle. These are discussed in detail in Section 7.3. Current planning indicates that some of the existing apparatuses and enclosures will be phased out and replaced with new and/or improved experiment hardware. The definition of the new improved apparatus and thermal enclosures that will be flown during the Space Station era are based on extrapolating the existing systems and incorporating the desired improvements specified in the Science Requirements Document. The facility definition will be based on the TBE APCGF Phase A study [19].

The method and/or experiment hardware and the degree and type of experiment monitoring and control are designated or described individually in Section 7.0 as necessary to clarify each sensitivity or cost impact evaluation.

3.0 TECHNOLOGY REQUIREMENTS

The significant technology improvements desired by the principal investigators were identified during the literature search. The technology items are related to two different areas: one is the technology associated with the growing of the crystals and the other is related to the techniques of analyzing the crystals either on the ground and on orbit. The items listed on Figure 3.0-1 are those that the investigators would like to see implemented in the coming years to improve both the reliability of growing crystals and quality of the grown crystals. In addition they would like to have the capability of analyzing the crystals on orbit immediately after the crystals have been grown. The technology requirements found were for the most part identified as goals with no particular target date identified for any individual item.

Several investigators are developing methods to eliminate the effects of the crystal contacting the vessel walls which can lead to heterogeneous nucleation [10] and possibly isolate the samples from the residual accelerations caused by the astronauts motions and the shuttle thruster firings . W.K. Rhim and S.K. Chung, JPL, are investigating the use of an electrostatic levitation system using

a containerless chamber [11]; R.L. Kroes, D.A Reiss, and S. L. Lehoczky, MSFC, are investigating the possibility of initiating growth of the crystals away from the container walls by injection of a hot, highly concentrated solution into a body of less-concentrated (but slightly supersaturated) growth solution [12]. Also, P. J. Shlichta, Caltech, is looking at a concept of electrostatic stabilization of growing crystals which combines the best features of the sandwich-drop and the electrostatic-levitation methods of support [13]. T. A. Nyce and F. Fosenberger, UAH, [14] are investigating a new technology in which crystals are freely suspended in the nutrient solution, eliminating container wall contact and maximizing the uniformity of the solute supply to the interface. All of these methods/concepts have been tested in the laboratory and show promise for future use, however, additional research and development is required before any of the hardware would be ready for flight.

Crystal Growing

- *** New Techniques for Growing Crystals**
  - **- Containerless**
  - **- Electrostatic Stabilization**
  - **- Growth of Crystals Away From Container Walls**
  - **- Freely Suspended Crystals in Nutrient Solution**
  - **- Compact Apparatus for Growth of Protein Crystals**
- *** Detect Start of Nucleation - Monitoring**
  - **- Direct Microscopy and Polarization**
  - **- Laser Light Scattering**
- *** Metering/Measuring Methods**
- *** Dynamic Control of Vapor Equilibration Process**
  - **- Temperature**
  - **- pH**
  - **- Protein Concentration**
  - **- Ionic Strength**
  - **- Precipitating Agent Concentration**
- *** Temperature Gradients to Affect Protein Solubility**
- *** Phase Diagrams for Proteins**

Crystal Analysis Techniques

- *** On Orbit Analysis**
  - **- In Situ X-Ray Diffraction Analysis**
- *** On Ground Analysis**
  - **- Two-dimensional NMR Spectroscopy**

Figure 3.0-1 Technology Requirements

The investigators would also like to have a better, simpler way of growing large number of crystals in a small apparatus. D.C. Carter and T.Y. Miller, MSFC, have developed a concept for a small, compact apparatus which contains 24 crystal-growth chambers in a 12- by 8- by 2-cm volume. It has few moving parts and can initiate and terminate the growth of the crystals at prescribed times automatically [15].

For successful crystallization it may become important to adjust growth parameters such as pH, vapor pressure, solution concentration, etc., just after nucleation. Detection of nucleation is thus an important step. Only non-invasive techniques for the detection of nucleation can be considered and optics is an excellent candidate. A. Choudry, UAH, has looked at several different techniques, one of which uses direct microscopy and polarization. The preliminary study results were encouraging and indicated that the technique was a very promising approach for detecting the start of nucleation that deserved additional studies [16].

In general, the investigators would like to have better methods of measuring the amounts of liquids used in the tests and to understand what is going on during the growing of the crystals (ie, better monitoring systems) and be able to change the conditions in real time (ie, dynamic control). Presently there is only about a 20 percent success rate of growing crystals in space. The development of hardware which allows protein crystal growth experiments to be optimized in microgravity should improve the success rate. Developments such as the use of laser light scattering to detect the onset on nucleation, dynamic control of the vapor equilibration process, use of temperature gradients to gently affect protein solubility, and the availability of phase diagrams for particular proteins will provide a better understanding of macromolecular crystal growth mechanisms and lead to the development of new and improved crystallization techniques [17].

4.0 SENSITIVITY PARAMETERS

As part of the literature search, the parameters that could be varied that would effect the operation and cost of the crystal growth apparatus were identified. The purpose of identifying these parameters was to determine those major parameters that, when changed, would significantly impact the cost of the development and/or operating an apparatus, enclosure, or facility. Figure 4.0-1 is a list of the parameters or improvements that the investigators would like to have the capability to change or modify in the future.

The two most important improvements that all investigators would like to have in the next generation of equipment are the capability to monitor and control the crystal growth in real time. Based on this, these two items and the other three items listed on Figure 4.0-1 in the larger bold type have been selected as the five basic science parameters that will be varied to determine their sensitivity on the total program. The resultant factors that are impacted as a result of changing these basic parameters are shown on Figure 4.0-2. Qualitative values have been added to each of the resultant factors as shown; quantitative values are determined in section 7.3.

CONTROL
- DYNAMIC
- CONTROLLED LOOP ANALYSIS
- REAL TIME
- STATIC
- PREPLANNED
- COMPUTER
- REMOTE

MONITORING
- ALL GROWTH PARAMETERS
- SELECTED PARAMETERS
- SELECTED RECORDING
- NO. OF CELLS
- REAL TIME
- INTERMITTENT
- CONTINUOUS
- VIDEO
- OPTICAL
- LASER LIGHT SCATTERING
- DIGITAL
- CAMERA
- REMOTE MICROSCOPE

SAMPLES, NO. OF
- PRODUCTION QUANTITIES
- <1000 +

SOLUTION[S]
- SUPERSATURATION
- CONCENTRATION
- IONIC STRENGTH
- PURIFICATION
- VOLUME[S]

TEMPERATURE
- RANGE
- STEADY STATE
- RAMP

ANALYSIS
- ON-ORBIT
- X-RAY DIFFRACTION
- NMR SPECTROSCOPY

DATA TRANSMISSION
- RECORDING
- STORAGE
- DOWNLINK
- UPLINK

GLOVE BOX
- MANIPULATE TO OPTIMIZE TECHNIQUES
- CRYSTAL MOUNTING [X-RAY FACILITY]
- EQUIPMENT MAINTENANCE
- HAZARDOUS MATERIAL HANDLING
- CRYSTAL STORAGE IN SEALED CAPILLARYS

GOALS
- DEV. DYNAMIC CONT. DIAGNOSTICS
- OPTIMIZE TECHNIQUES
- SELECT MOST BENEFICIAL TECHNIQUES/ PARAMETERS
- DATA / THEORY COMPARISON: 1g / "0"g
- NEW PROTEINS

GROWTH, CRYSTAL
- RATE
- EXTENDED TIMES
- DURATION

MULTI-USE
- CONTINUOUS / REPEATED OPERATION
- DIFFERENT PROTEIN
- DIFFERENT CONDITIONS
- DIFFERENT CONCENTRATIONS
- FLUSH

NUCLEATION
- SEEDING
- DETECTION
- THERMALLY INDUCED
- pH INDUCED
- TEMPERATURE
- SOLUBILITY
- MULTIPLE
- ADDITIVES / SIDE EFFECTS

OPERATIONS
- MANTENDED
- AUTOMATION
- NON INVASIVE OPERATIONS

pH
- RANGE
- STEADY STATE
- RAMP

QUENCH
- WAYS TO
- STABILIZE

RELATIVE HUMIDITY

ROBOTICS
- PUMPING
- FLUSH
- CHANGE CONCENTRATIONS
- CHANGE BATCHES
- SELF CONTAINED STORAGE
- REUSE

PRESERVATION METHOD
- MODERATE TEMP
- IN SOLUTION
- OTHER
- CRYOGENIC

VIBRATION
- DESIGN / CAUSES
- MONITOR
- CONTROL

Figure 4.0-1 Basic Sensitivity Parameters/Factors

Sensitivity Parameters

Basic Parameters

0 Monitor - Video to Detect Nucleation - Enclosure/Apparatus Design Impact

Present	Desired
- TV - Small Number of Samples	- TV for Every Sample
- Temperature	- Relative Humidly
- Pressure	- Temperature
- pH	

Resultant
- Complexity Increases
- Power - Increases
- Weight -Increases
- Volume - Remains Fixed
- CDMS - Increases
- Costs - Increases

0 Control - Temperature - Enclosure Design Impact
- Solution Concentration - Apparatus Design Impact

Present	Desired
- Control Temperature at Fixed Value	- Vary Temperature as Desired from 1°C to 60°C at ± 0.02°C
-Control Solution Concentration at Present Value	-Vary Concentration as Desired

Resultant
- Complexity - Increases
- Power - Increases
- Weight - Small Increase
- Volume - Remains Fixed
- CDMS - Increases
- Cost - Increases

Figure 4.0-2 Basic and Resultant Parameters

0 Temperature - Enclosure Design Impact

Present	Desired
- Fixed at Preset Value	- Vary as Desired from 1°C to 60°C at ± 0.02°C

Resultant
- Complexity - Increases
- Power - Increases
- Weight - Small Increase
- Volume - Remains Fixed
- CDMS - Increases
- Cost - Increases

0 Vary Solution Concentration - Apparatus Design Impact

Present	Desired
- No Capability to Vary	- Vary by Preprogrammed Command - Vary by real Time Command

Resultant
- Complexity - Increases
- Power - Increases
- Weight - Increase
- Volume - Fixed
- CDMS - Increases
- Cost - Increases

0 Increase Number of Samples - Apparatus Design Impact

Present	Desired
- 80 Samples	-1500 Samples

Resultant
- Complexity - Increases
- Power - Increases
- Weight - Increase
- Volume - Fixed
- CDMS - Increases
- Cost - Increases

Figure 4.0-2 Basic and Resultant Parameters (Continued)

5.0 INVESTIGATOR INTERVIEWS

Several crystal growth scientists/investigators, as shown on Figure 5.0-1, were identified for potential interviews to discuss the advantages and disadvantages of their preferred methods of growing crystals in space and of their preferred type of hardware. However, due to the NASA Research Announcement (NRA) that was released last year, and the competition resulting from this NRA, it was concluded that it would not be appropriate to talk to the principal investigators until after the NRA selections have been made.

- ONE - TWO INTERVIEWS PER SELECTED METHOD

METHOD	INVESTIGATOR
VAPOR DIFFUSION:	BUGG, C.E.
	DELUCAS, L.U.
LIQUID DIFFUSION:	FEIGELSON, R.S.
	MCPHERSON, A
	SNYDER, R.
	PUSEY, M.
	NYCE, T
DYNAMICALLY CONTROLLED;	ROSENBERGER, F.
	CARTER, D.

- ONE - TWO INTERVIEWS PER OTHER METHOD

BATCH:	ARROTT, A.
	FARBER, G.
CONTAINERLESS:	RHIM, WON-KYU
DIALYSIS:	SIEKER, L. C.

Figure 5.0-1 Potential Investigator Interviews

Discussions were held with NASA engineers and scientists to determine the types of hardware (facilities, thermal enclosures, and apparatuses) that should be considered; and to establish the baseline APCG program and program options being proposed by NASA that should be considered in the study. Of particular importance were the desired improvements in the crystal growth apparatus and thermal enclosures to be used during the Space Station era. The transition from the Shuttle to the man tended phase of the Space Station and its impact on the permanently manned Space Station era facilities and hardware was defined. The three apparatuses selected from the on going NRA competition will be the primary hardware utilized during the transition period. It was also established that two Announcements of Opportunity (AO) were planned; the first AO would request that a new Core Facility, a new thermal enclosure system, and four new apparatuses be developed for flight in 1998, with the second AO requesting that a second new Core Facility , another new thermal enclosure system and four more new apparatuses be developed for flight in the year 2000. Each successive development would incorporate improvements and new capabilities over the

preceding developments. These discussions and information exchanges therefore formed the basis for proceeding with development of the program scenarios.

6.0 CRYSTAL GROWTH PROGRAM DEVELOPMENT

A baseline and four alternate program scenarios, Figure 6.0-1, have been developed covering the APCG-T (Advanced Protein Crystal Growth - Transition), and the new APCG-F (APCG - Facility) time frames. These scenarios provide for early APCG transition flights to the Space Station Freedom beginning in either December 1996 or May 1997. The APCG-F phase one MTC (man tended configuration) flights begin as early as November 1998 and as late as November 2000 with the phase two APCG-F, PMC (permanently manned configuration) flights beginning as early as November 2000 and as late as November 2003. There are a total of eleven new apparatuses, two new enclosures, and two new or upgraded facilities incorporated in these program scenarios.

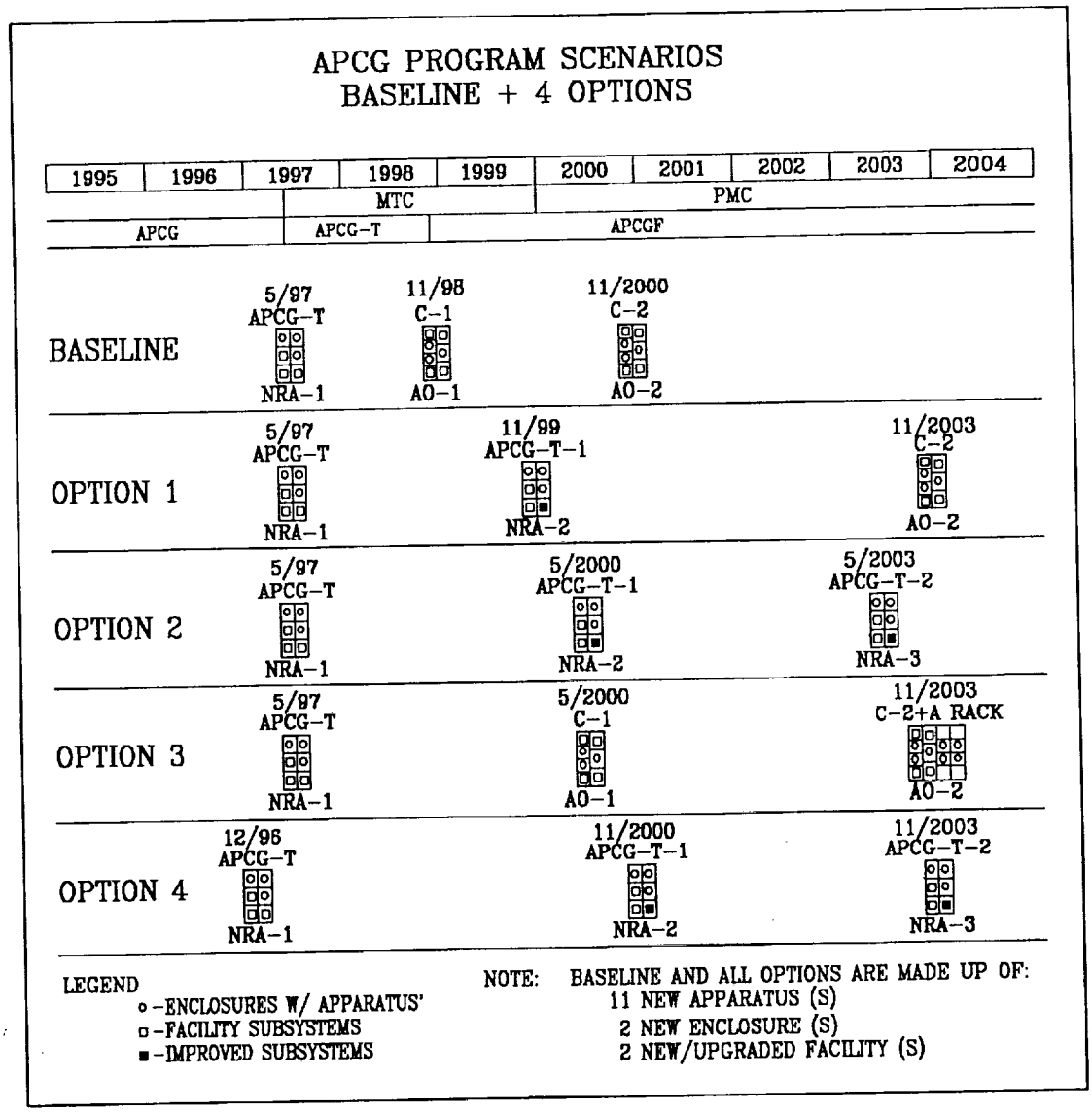


Figure 6.0-1 APCG Program Scenario-Baseline + 4 Options

The baseline program was developed to establish a benchmark to build on or compare to when identifying and evaluating the optional programs. It is in no way intended to represent the protein crystal growth program planned by NASA. It has a set launch date for each of the crystal growth hardware configurations. The four options were developed to provide easy identification and comparison of both programmatic and scientific impacts caused by selected variations.

Background information: It was assumed that the hardware acquired through the new AO's would be the same as that acquired through the NRA process with the exception of the core facility. It was also assumed that the total program experiment capability would be identical regardless of the procurement process.

The planned baseline program accomplishments and each of the four optional programs evaluated in this study are therefore scientifically equal; the selected schedule changes (only) in the alternate scenarios separate each program scenario option from the others. For example, reading Figure 6.0-1 vertically, the baseline mission beginning in 11/1998 has the same science capabilities as the option 4 mission in 11/2000 (middle "column", top to bottom), it was assumed that:
1- the baseline and option 3 AO-1 apparatus(s) was therefore equal in capability to options 1, 2 and 4 NRA-2 apparatus[s];
2- the baseline and option 3 AO-1 enclosure was equal in capability to options 1,2, and 4 NRA-2 enclosure and;
3- the baseline and option 3 AO-1 new facility was equal to options 1, 2 and 4 NRA-2 modified facility. The same total-program-capability logic also applies to the left and right "columns" (Figure 6.0-1).

The same scenario capability definition information is also shown on Figure 6.0-2 and is perhaps more easily understood by simultaneous examination of both Figures 6.0-1 and 6.0-2. The facility developed new under an AO, was assumed to have the same scientific capabilities as that of an existing facility modified or upgraded under an NRA i.e., the two modified facilities, APCG-T-1 and APCG-T-2 listed under NRA-2 and NRA-3, (Figure 6.0-2) are technically equivalent to the two new facilities, Core-1 (C-1) and Core-2 (C-2) listed under AO-1 and AO-2 respectively. And, a new experiment apparatus [or new enclosure], whether developed under AO or NRA, was assumed to incorporate the same capabilities. The C-1 and C-2 capabilities were defined in The Teledyne Brown Engineering Phase A study, References 19 and 39. The APCG-T-1 facility capability is based on a Boeing Company Concept Study, Reference 43. Summary definitions of these experiment hardware capabilities are described in Section 7.0.

APCG PROGRAM
SCENARIO OPTION DEFINITIONS

ANNOUNCEMENT	NRA-1	NRA-2	NRA-3	AO-1	AO-2
HARDWARE / AMOUNT					
-New Apparatus	3	4	4	4	4
-New Enclosure	0	1	1	1	1
-New Facility	0	0	0	1	1
-Mod Facility	APCG-T	YES	YES	NO	NO

New Facility	-Includes new structure and new, improved subsystems.
Mod Facility	-Includes only minimum improved subsystems to accommodate the new apparatus and enclosure.
APCG-T	-The facility defined by The Boeing Company.
APCG-T-1	-Improvements to the original facility subsystems without any structural changes.
APCG-T-2	-Additional subsystem improvement, still no structural changes.
C-1	-The facility defined by TBE in the CODR. A new structure and new subsystems.
C-2	-A new facility with new structure and subsystems. Improved capability compared to C-1.

Figure 6.0-2 APCG Program Scenario Option Definitions

APCG-T (Transition) The Advanced Protein Crystal Growth Transition (APCG-T) hardware will be developed so that the experiment apparatus and the thermal enclosures previously flown on the Shuttle and Spacelab can be flown on the SSF without extensive modification. The data management system for the APCG-T will closely resemble the concept being considered for the APCGF C-1,(i.e. video provided, automated loading, etc.). The only difference between the APCG-T and the APCGF C-1 (or APCG-T-1) is the new structure and any improvements that might occur in the subsystems in the 1.5 years between the two initial flights. Existing crystal growth experiment apparatuses and enclosures (domestic and foreign) previously developed for flight on the Shuttle and Spacelab, including the three new apparatuses from the 1991 NRA, will be used thereby limiting science capabilities to those provided during the PCG and APCG projects. Modifications to accommodate improved microgravity science capability will not be included.

APCGF - Phase 1: The November 1998 flight will provide increased science capability. Four new experiment apparatus systems, one new thermal enclosure system and one new [or improved] SSF core facility C-1 (or APCG-T-1) will be developed. This hardware will meet the new science requirements selected form

the Advanced Protein Crystal Growth Facility (APCGF) phase one Announcement of Opportunity (or NRA-2) planned for 1992/1993. The new or improved facility has the capability to accommodate thermal enclosures twice the size of the TES.

APCGF - Phase 2: The November 2000 permanently manned SSF flight will include development of an additional four new experiment apparatus systems, one additional new thermal enclosure system, and one new [or improved] SSF core facility C-2 (or APCG-T-2). The contract TM also groundruled that option 3 include the development of an auxiliary rack (ARACK) during phase 2 evaluation. The ARACK was considered to supply additional experiment volume only - not any increased technological capability. This APCGF phase two hardware will be developed to meet new science requirements selected from an Announcement of Opportunity AO-2 (or NRA-3) planned for release in 1994/1995. The ARACK has the capability to accommodate thermal enclosures four times larger than the TES.

6.1 Baseline Scenario

The baseline protein crystal growth program scenario was established providing initial Space Station Freedom (SSF) flights beginning in May 1997 using the APCG-T (transition) facility and new experiment apparatuses designed during the NRA-1 time frame. It also provides for SSF flights beginning November, 1998 using the new C-1 (APCGF) facility capable of accommodating the additional new experiments and new thermal enclosure developed under AO-1 (Announcement of Opportunity - 1); and provides a further improved C-2 facility in November, 2000 capable of accommodating the additional new experiment apparatuses and enclosure developed under AO-2. Figure 6.0-1 is a graphical representation of the baseline and four alternate program scenarios evaluated in this study. The four alternate options are explained below.

6.2 Option 1

This option maintains the early SSF flights beginning in May, 1997 but delays development and flight of the phase one activities one year, resulting in the NRA-2 flights beginning in November, 1999. The option relies on incremental development changes to improve the APCG-T facility capabilities for the phase one flights. The experiment hardware developed under NRA-2 is, by groundrule, capable of supporting identical experiments for this time frame whether developed under NRA or AO. Phase two hardware development is delayed three years compared to the baseline program; flights begin in November, 2003.

6.3 Option 2

This option also maintains the early first SSF flights beginning in May 1997, and assumes that the APCG-T-1 facilities have the same capabilities as those in Option1, but the improvements have been delayed an additional 6 months between APCG-T and the APCG-T-1 due to budget constraints. However, the period between phase one and two (APCG-T-1 and APCG-T-2) was shortened one year compared to option 1. Option 2 was also constructed entirely using ..

NRA procurement processes. This option eliminates the new hardware core facilities (C-1 and C-2) and relies on incremental development changes to improve the APCG-T hardware capabilities. These improvements provide the same subsystems capability (power, data management, video etc) as planned for the Core C-1 and C-2.

6.4 Option 3

The APCG-T in 5-97 has the same capability as that in the Baseline Option. There is a one and one-half year delay in the AO-1 experiment apparatus and enclosure development to May 2000 for a total time of 3 years between the first APCG-T flight and the first flight of the new AO-1 hardware. In addition, there is a 3 year delay until November 2003 for the AO-2 experiment apparatus and enclosure development and flight (as compared to the Baseline Option). Also, the Auxiliary RACK is incorporated in this option. The experiment apparatuses and enclosures developed under NRA-1, AO-1 or AO-2 can be flown in the ARACK. Some interface modification is required if the ARACK is used with a C-1 facility, but no mods are necessary when used with the C-2 facility since development would be concurrent. Addition of the ARACK would allow the use of an additional four TES size experiments or one experiment four times TES size.

6.5 Option 4

This option assumes continuation of the APCG experiments with the transition phase moved six months sooner compared to the baseline, beginning in December 1996. Anticipated budget constraints eliminate AO-1 and AO-2. All experiment and facility development will be done under NRA procedures as in option 2. There is an additional 6 months delay in beginning phase 1 (compared to option2); a total of three years and eleven months from beginning APCG-T to beginning of phase 1. Phase 2 begins November 2003, the same as options 1 and 3.

7.0 SENSITIVITY PARAMETER MODIFICATION AND RESULTANT IMPACTS

The program scenarios developed in Section 6.0 were based on general STS launch schedules, budget constraints and hardware procurement procedures. These scenarios are generically depicted on Figures 6.0-1 and 6.0-2. In order to determine the cost/programmatic and scientific impact of the selected parameter variations, the details of what is to be flown in those program scenarios are defined in this section in terms of experiment hardware capabilities resulting from evaluation of the modified parameters. These capability requirement modifications and the resulting experiment designs are discussed and summarized in the following paragraphs.

7.1 Basic Parameters

The crystal growth experiments are defined in terms of the combined capabilities of each basic parameter during each of the three hardware configuration eras labeled NRA-1, AO-1/NRA-2, and AO-2/NRA-3 as shown on Figure 7.1-1. The five basic parameters were initially identified in Section 4.0 (Figure 4.0-1). Each parameter is now assigned a baseline "range" of capabilities and these are also

presented in tabular format on Figure 7.1-1 reading each row left to right. The range of capabilities and scientific benefits for each parameter was selected to incrementally increase as time progresses. As an example, the baseline number of cells video monitored was incrementally increased from six to 100 as a function of the time era. The magnitudes of these increments were chosen as logical steps from present capabilities to the SCD [18] stated requirements.

SELECTED
BASIC PARAMETERS

BASIC PARAMETER \ ERA	PRESENT	NRA-1 (3 APP'S.)	AO-1/NRA-2 (4 APP'S.) (1 ENC.) (1 FAC.)	AO-2/NRA-3 (4 APP'S.) (1 ENC.) (1 FAC.)
MONITORING VIDEO (APPARATUS)	6 CELLS 6 CAMERAS RECORDED	20 CELLS RECORDED	50 CELLS REALTIME	100 CELLS REALTIME
CONTROL (APPARATUS) (ENCLOSURE) (FACILITY)	START MANUAL STOP MANUAL	START AUTO. PREPL. STOP AUTO. PREPL.	START AUTO. PREPL. STOP AUTO. PREPL. VARY TEMP. PREPL. VARY SOL.CONC. PREPL.	START REAL-TIME STOP REAL-TIME VARY TEMP. REAL-TIME VARY SOL.CONC. R-TIME
TEMPERATURE (ENCLOSURE)	1° - 40° C ± 0.1° C PRESET	1° - 40° C ± 0.05° C PRESET	1° - 40° C ± 0.05° C RAMP PREPLANNED	1° - 60° C ± 0.02° C RAMP REALTIME
SOLUTION CONCENTRATION (APPARATUS)	PRESET	PRESET	VARY PREPLANNED	VARY REALTIME
NUMBER OF SAMPLES (APPARATUS)	4 X 20 = 80	200	500	1000

Figure 7.1-1 Selected Basic Parameters

7.2 Modifications to Basic Parameters

In addition to these baseline parameter variations shown on Figure 7.1-1, several other viable increments within each era were initially considered for evaluation. Most of which if not selected as parameter baseline characteristics (Figure 7.1-1), were picked to be evaluated as optional parameter capabilities and are shown on Figures 7.2-1 through 7.2-5. These basic parameter modification combinations result in a total of eleven specific experiment capabilities evaluated. Some of these selected configurations exceed the requirements put forth in the SCD [18], but were retained for evaluation to better illustrate the sensitivities of each. These, along with the baseline variations on Figure 7.1-1, are shown on Figures 7.2-1 through 7.2-5 as "boxed" capabilities.

Development of optional experiment definitions in terms of the consequential changes to the resultant (Section 4, Figure 4.0-2) parameters was accomplished as the next step toward evaluation of the program sensitivity impacts. Examination of Figures 7.2-1 through 7.2-5 reveals the magnitude of each of these additional basic parameter capabilities selected for evaluation during the three configuration eras.

For example, reading horizontally, Figure 7.1-1 depicts one of the three new experiment apparatuses planned during the NRA-1 era as having the video monitoring capability of 20 cells recorded; Figure 7.2-1 reading vertically, shows the other two monitoring capabilities available during the NRA-1 era (boxed in), as 30 cells recorded and 200 cells recorded. Figure 7.1-1 also shows one of the four new experiment apparatuses planned during the AO-1/NRA-2 era as having the monitoring capability of 50 cells real-time; and one of the (additional) four new experiment apparatuses planned during the AO-2/NRA-3 era as 100 cells real-time. These capabilities are depicted as baseline values on Figure 7.2-1 which also shows the option 4 monitoring capabilities as 500 cells real-time and 1500 cells real-time respectively. Figures 7.1-1 through 7.2-5 represent each experiment capability from baseline through each option in this same manner. As stated, the basic parameter capability magnitudes were selected to include, but not be limited to, all of the desired capabilities outlined in the SCD [18]. The additional rationale used in these individual magnitude selections is summarized in the following paragraphs.

Monitoring - Figure 7.2-1: The total range of video monitoring of 20 to 1500 crystal growth cells was selected; either recorded for later analysis or viewed real-time. Video recordings are made in either case. Impact evaluation of this parameter was limited to video - no other form of monitoring, e.g.real-time, manual, etc. was considered. The assumption was made that the total number of cells and required video be contained within one experiment. This may increase the need for miniaturization unduly and is presented only for clarification, not as a recommendation. This assumption also increased the

BASIC
PARAMETER VARIATION

MONITORING

OPTION \ ERA	PRESENT	NRA-1	AO-1/NRA-2	AO-2/NRA-3
BASELINE	6 CELLS 6 CAMERAS RECORDED	20 CELLS RECORDED	50 CELLS REALTIME	100 CELLS REALTIME
OPTION 1	6 CELLS 6 CAMERAS RECORDED	30 CELLS RECORDED	50 CELLS REALTIME	100 CELLS REALTIME
OPTION 2	6 CELLS 6 CAMERAS RECORDED	20 CELLS RECORDED	75 CELLS REALTIME	100 CELLS REALTIME
OPTION 3	6 CELLS 6 CAMERAS RECORDED	20 CELLS RECORDED	50 CELLS REALTIME	150 CELLS REALTIME
OPTION 4	6 CELLS 6 CAMERAS	200 CELLS RECORDED	500 CELLS REALTIME	1500 CELLS REALTIME

Figure 7.2-1 Basic Parameter Variation-Monitoring

complexity rating. However, it was felt that evaluation of this demanding condition was justified as an impact driver. Additional rationale explanation is offered in section 7.3.

Control - Figure 7.2-2: Four functions were accounted for while evaluating the impacts of control during preplanned and real-time operation - experiment start and stop, temperature ramp (yes or no), and solution concentration variation (yes or no). The real-time operation evaluated was controlled remotely.

BASIC
PARAMETER VARIATION

CONTROL

ERA / OPTION	PRESENT	NRA-1	AO-1/NRA-2	AO-2/NRA-3
BASELINE	START MANUAL STOP MANUAL	START AUTO. PREPL. STOP AUTO. PREPL.	START AUTO. PREPL. STOP AUTO. PREPL. VARY TEMP. PREPL. VARY SOL. CONC. PREPL.	START REAL-TIME STOP REAL-TIME VARY TEMP. REAL-TIME VARY SOL. CONC. R-TIME
OPTION 1	START MANUAL STOP MANUAL	START AUTO. PREPL. STOP AUTO. PREPL. VARY TEMP. PREPL. VARY SOL CONC PREPL	START AUTO. PREPL. STOP AUTO. PREPL. VARY TEMP. PREPL. VARY SOL. CONC. PREPL.	START REAL-TIME STOP REAL-TIME VARY TEMP. REAL-TIME VARY SOL. CONC. R-TIME
OPTION 2	START MANUAL STOP MANUAL	START AUTO. PREPL. STOP AUTO. PREPL.	START AUTO. PREPL. STOP REALTIME VARY TEMP AUTO PREPL VARY SOL. CONC. R-TIME	START REAL-TIME STOP REAL-TIME VARY TEMP. REAL-TIME VARY SOL. CONC. R-TIME
OPTION 3	START MANUAL STOP MANUAL	START AUTO. PREPL. STOP AUTO. PREPL.	START AUTO. PREPL. STOP AUTO. PREPL. VARY TEMP. PREPL.	START REAL-TIME STOP AUTO. PREPL. VARY TEMP AUTO PREPL VARY SOL. CONC. PREPL.
OPTION 4	START MANUAL STOP MANUAL	START AUTO. PREPL. STOP AUTO. PREPL.	START AUTO. PREPL. STOP AUTO. PREPL. VARY TEMP. PREPL.	START REAL-TIME STOP AUTO. PREPL.. VARY TEMP. REAL-TIME VARY SOL. CONC. R-TIME (2 STAGES)

AUTO. PREPL. - AUTOMATIC PREPLANNED
PREPL - PREPLANNED
SOL. CONC. - SOLUTION CONCENTRATION
TEMP. - TEMPERATURE
R-TIME - REAL-TIME

Figure 7.2-2 Basic Parameter Variation-Control

Temperature - Figure 7.2-3: Two operating ranges, two accuracy requirements, and one temperature ramp were evaluated for impact during preplanned and real-time operation. It was assumed that the temperature would be logged for post experiment analysis. The weight and power requirements for logging are included in the total values but not separately identified. Under actual conditions, and at little or no additional "cost", real-time video cell monitoring, if already provided, as mentioned above, could probably aid significantly during real-time ramp procedures.

The total power and weight requirements for control settings and temperature maintainance were calculated during this assessment. The temperature

maintainance impacts are assigned to the enclosure, while setting and accuracy impacts are put against the apparatus design.

BASIC
PARAMETER VARIATION

TEMPERATURE

ERA / OPTION	PRESENT	NRA-1	AO-1/NRA-2	AO-2/NRA3
BASELINE	1° - 40° C ± 0.1° C PRESET	1° - 40° C ± 0.05° C PRESET	1° - 40° C ± 0.05° C RAMP PREPLANNED	1° - 60° C ± 0.02° C RAMP REALTIME
OPTION 1	1° - 40° C ± 0.1° C PRESET	1° - 40° C ± 0.05° C RAMP PREPLANNED	1° - 60° C ± 0.05° C RAMP PREPLANNED	1° - 60° C ± 0.05° C RAMP REALTIME
OPTION 2	1° - 40° C ± 0.1° C PRESET	1° - 40° C ± 0.05° C PRESET	1° - 40° C ± 0.02° C RAMP REALTIME	1° - 60° C ± 0.02° C RAMP REALTIME
OPTION 3	1° - 40° C ± 0.1° C PRESET	1° - 40° C ± 0.05° C PRESET	1° - 60° C ± 0.05° C RAMP PREPLANNED	1° - 60° C ± 0.05° C RAMP PREPLANNED
OPTION 4	1° - 40° C ± 0.1° C PRESET	1° - 40° C ± 0.05° C PRESET	1° - 60° C ± 0.05° C RAMP PREPLANNED	1° - 60° C ± 0.05° C RAMP REALTIME

Figure 7.2-3 Basic Parameter Variation-Temperature

Solution concentration - Figure 7.2-4: The impact of one and/or two concentration adjustments, either preplaned or real-time was evaluated. It was assumed that during real-time operation, this change(s) could be made at any time during the experiment but the desired magnitude of the concentration change had been set in advance. Again, as in the case of temperature control, at little or no additional "cost", a side benefit of real-time video monitoring could probably be used to aid in this procedure.

BASIC
PARAMETER VARIATION

SOLUTION CONCENTRATION

OPTION \ ERA	PRESENT	NRA-1	AO-1/NRA-2	AO-2/NRA-3
BASELINE	PRESET	PRESET	VARY PREPLANNED	VARY REALTIME
OPTION 1	PRESET	VARY PREPLANNED	VARY PREPLANNED	VARY REALTIME
OPTION 2	PRESET	PRESET	VARY REALTIME	VARY REALTIME
OPTION 3	PRESET	PRESET	PRESET	VARY PREPLANNED
OPTION 4	PRESET	PRESET	PRESET	VARY REALTIME 2 STAGES

Figure 7.2-4 Basic Parameter Variation-Solution Concentration

Number of samples - Figure 7.2-5: The overall impact of varying experiment capability from 200 < 1500 crystal growth cells was analyzed. Six distinct capacities including these two limits were evaluated. The assumption was made that the total number of cells being impact evaluated would be contained within one experiment. This is felt to be a reasonable requirement in itself, but when imposed in conjuction with the video monitoring, may increase the complexity and the requirement for miniaturization unduly. However, since large quantities is one of the SCD [18] requirements, the demanding condition was evaluated.

BASIC
PARAMETER VARIATION

NUMBER OF SAMPLES

OPTION \ ERA	PRESENT	NRA-1	AO-1/NRA-2	AO-2/NRA-3
BASELINE	4 X 20 = 80	200	500	1000
OPTION 1	4 X 20 = 80	100	200	500
OPTION 2	4 X 20 = 80	200	750	1000
OPTION 3	4 X 20 = 80	200	500	750
OPTION 4	4 X 20 = 80	200	500	1500

Figure 7.2-5 Basic Parameter Variation-Number of Samples

7.3 Resultant Parameters

With the basic parameter variations now defined in detail, the consequent impacts to each resultant parameter within each experiment configuration can be determined. When these impacts, expressed in terms of mass, power, complexity, cost, etc. are matched with their particular configuration requirements, a crystal growth experiment is "designed" for purposes of this study. In order to insure uniform impact determination and evaluation, the following set of guidelines establishing the rationale and practical limits or boundaries was created.

The experiment "designs" were developed using existing data or extrapolation of existing data when available. The existing U.S. apparatus and enclosure data available are represented by the summarized requirements and capabilities shown on Figures 7.3-1 through 7.3-5. Existing foreign experiments which combine the functions of both apparatus and enclosure are shown on Figures 7.3-6 and 7.3-7. The facility data was based on descriptions contained in references 19, 39, and 43. These references and references, 40, 41, and 42 were also used in defining the experiments.

Calculations and estimates based on extrapolation were made, where possible, based on the same type of support equipment (mounting brackets, lights, switches, wire, interface ports etc.) as could be identified in the existing data. When extrapolation of existing requirements and capabilities did not seem reasonable, due to the lack of a basis of similar data, estimates were made based on "experience and best engineering judgement". Preliminary graphs and tables were constructed to supplement existing data. Graphs of mass vs. number of samples; power vs. number of samples; power vs. thermally controlled mass; power per unit mass vs. thermally controlled mass; and power (and mass) vs. number of samples monitored (or otherwise controlled) were constructed to help make cursory definitions of the experiment designs. These supplemental data were created for a wide range of experiment conditions such as real-time, recorded, preset, preplanned/automatic etc.

Once the basic indicators for mass and power requirements were identified, additional estimated requirements such as number of commands, average experiment densities, function sharing, reasonable limits on number of cells per monitor, and several more, were over-layed on the charts and graphs to help increase our confidence that all pertinent data had been considered to the extent possible.

Mass and power requirements were selected for evaluation first since they are considered the most directly effected. Each experiment is treated as a point design and therefore tailored for the particular capabilities selected i.e., the power and mass impact calculations are scoped to include only those requirements which can be identified for the particular basic (and resultant) parameter(s) capabilities being considered. Hence, power and mass estimates may be optimistically low; if so, they should be uniformly so. No attempt was made to integrate these designs except where physical size dictated i.e., the

APPARATUS
SUMMARY DESCRIPTION
VAPOR DIFFUSION APPARATUS

- VDA -

DEVELOPER:	NASA/MSFC
DESCRIPTION:	VAPOR DIFFUSION
DIMENSIONS [D x W x H] - CM	~33 x 25.4 x 5.1 (DIMENSION H INCLUDES ALLOWANCE FOR SUPPORTS & CLEARANCE)
MASS - Kg:	~5.7
PROTEIN VOLUME - µl	800 [40 PER DUAL SYRINGE x 20]
POWER REQUIREMENTS - WATTS:	-
VOLTAGE - VOLTS:	-
NUMBER OF SAMPLES:	20 PER TRAY
MONITORING CAPABILITY:	AT-HAND
SOLUTION CONCENTRATION -	
MONITORING:	-
CONTROL:	PRESET
TEMPERATURE REQUIREMENTS:	ENCLOSURE FUNCTION
MONITORING:	NA
CONTROL:	PRESET
RANGE - °C:	22
ACCURACY - °C:	± 0.1
RAMP:	NO
CONTROL CAPABILITY:	MANUAL, START & STOP
COST:	$1,382,250

Data Source:
1. APCGF Science Package, Teledyne Brown Engineering, Jan., 1992
2. MSFC instrument interface aggreement JA-85.
3.. UAB familiarization training session for SpaceHab -1 presentation charts May, 1992

Figure 7.3-1 Existing Experiment Hardware-VDA

APPARATUS
SUMMARY DESCRIPTION
CRYSTAL OBSERVATION SYSTEM

- COS -

DEVELOPER:	UAB [NAS8-3611]
DESCRIPTION:	MODIFIED VDA, VAPOR DIFFUSION
DIMENSIONS [D x W x H] - CM:	NA [~22] x19.8 x 16.5 [REPLACES 4 VDA TRAYS]
MASS - Kg:	11.3
PROTEIN VOLUME - µl	NA
POWER REQUIREMENTS - WATTS:	12 [OWN EXTERNAL BATT. PACK x 2; 115 BACKUP]
VOLTAGE - VOLTS:	15 D CELL BATTERIES
NUMBER OF SAMPLES:	6
MONITORING CAPABILITY:	6 CCD CAMERAS, REAL-TIME OBSERVATION; RECORDING DOWNLINK, SAMPLE RATE: 3 - 5 MINUTE PERIODS DAILY
SOLUTION CONCENTRATION - MONITORING:	NA
CONTROL:	PRESET
TEMPERATURE REQUIREMENT - MONITORING:	ENCLOSURE FUNCTION RECORDED, 30 DAY MEMORY, CREW CHECKS DAILY
CONTROL:	PRESET
RANGE - °C:	1 - 40
ACCURACY -°C:	± 0.1
RAMP:	NO
CONTROL CAPABILITY:	ALL MANUAL- DIRECT MECH. FEED-THROUGH TO COS COMPONENTS - 10 CONTROLS: SYRINGE, CAMERA CIRCUIT, CAPPING, FOCUSING, CAMERA SWITCHER, POWER IN, & VIDEO OUT
COST:	NA

Data Source:
1. ICD-SH-TES/COS-001, May 1992
2. COS, Phase II Flight Hazard Analysis & Safety Compliance Data Package, UAB, Dec.,1991
3. Familiarization Briefing for SPACEHAB-1, May, 1992

Figure 7.3-2 Existing Experiment Hardware-COS

ENCLOSURE
SUMMARY DESCRIPTION
REFRIGERATOR / INCUBATION MODULE

- R/IM -

DEVELOPER:	McDAC
DESCRIPTION:	ENCLOSURE (SPACE OF ONE MID-DECK LOCKER
DIMENSIONS [D x W x H] - CM:	INTERIOR[2] - 36.8 x 25.4 x 16.5 EXTERIOR[1] - 49.5 x 50.8 x 27.9
MASS - Kg	EMPTY - 15.9 PAYLOAD - <15.9
POWER REQUIREMENTS - WATTS:	ENCLOSURE - 84 EXPERIMENT - NA
VOLTAGE - VOLTS:	28 ± 4
NUMBER OF SAMPLES:	60 [3 VDA TRAYS], OTHER TBD
MONITORING CAPABILITY:	TEMPERATURE - MANUAL
SOLUTION CONCENTRATION -	(APPARATUS FUNCTION)
MONITORING:	NO
CONTROL:	NO
TEMPERATURE -	
MONITORING:	MANUAL
CONTROL:	TEU, FAN FORCED CONVECTION
RANGE - °C:	4 - 37.5
ACCURACY -°C:	±0.2
RAMP:	NO
CONTROL CAPABILITY:	TEMPERATURE - MANUAL
CDMS REQUIREMENTS:	NA
COST:	NA

Data Source:
1. Personal contact - Ms. B Herren, NASA - MSFC.
2. Teledyne Brown Engineering, APCGF Science Package.Jan. 1992
3. NASA ICD A-21058

Figure 7.3-3 Existing Experiment Hardware-R/IM

ENCLOSURE
SUMMARY DESCRIPTION
COMMERICAL REFRIGERATOR / INCUBATION MODULE

- C-R/IM -

DEVELOPER:	SII / UAB
DESCRIPTION:	ENCLOSURE (SPACE OF ONE MID-DECK LOCKER)
DIMENSIONS [DxWxH] - CM:	INTERIOR - 37.1 x 25.4 x 16.5 EXTERIOR - 54.1 x 45.9 x 26.9
MASS - Kg	EMPTY - 14.5 PAYLOAD - < 22.7
POWER REQUIREMENTS - WATTS:	ENCLOSURE - 100 EXPERIMENT - NA
VOLTAGE - VOLTS:	24 OR 28
NUMBER OF SAMPLES:	60 [3 VDA TRAYS], OTHER - TBD
MONITORING CAPABILITY:	FRONT PANEL - TEMPERATURE & SETPOINTS, SAMPLE RATE - NA
SOLUTION CONCENTRATION -	APPARATUS FUNCTION
MONITORING:	NO
CONTROL:	NO
TEMPERATURE -	
MONITORING:	< 10 TEMP.SENSORS, PROGRAMMABLE LOGGER [BATTERY BACKUP]
CONTROL	TED's, FAN FORCED CONVECTION
RANGE - °C	4 - 40, SETPOINT EVERY 0.1
ACCURACY - °C:	0.5
RAMP	PREPROGRAMMED, MAGNITUDE - NA
CONTROL CAPABILITY:	MANUAL TEMP. COMMANDS VIA FRONT PANEL OR PREPROGRAMMED, TED's USED, FAN OPTIONAL
CDMS REQUIREMENTS:	NA
COST:	$512,000

Data Source:
1. Space Industries International Inc., brochure
2. ICD-SH-CR/IM/VDA-001

Figure 7.3-4 Existing Experiment Hardware-C-R/IM

ENCLOSURE
SUMMARY DESCRIPTION
THERMAL ENCLOSURE SYSTEM

- TES -

DEVELOPER:	SII / UAB
DESCRIPTION:	ENCLOSURE (SPACE OF 2 MID-DECK LOCKERS; 20 FLIGHTS REUSE)
DIMENSIONS [DxWxH] - CM:	INTERNAL - 35.6 x 25.4 x 25.4 EXTERNAL - 50 x 44.9 x 60
MASS - Kg	EMPTY - 32 PAYLOAD - < 22.7
POWER REQUIREMENTS - WATTS:	ENCLOSURE - 100, PEAK POWER TO TES INCREASED TO 240W TO ACCOMMODATE ELU,VIDEO UNITS & 12Vdc/5Vdc CONVERTER[4] EXPERIMENT - 15
VOLTAGE - VOLTS:	28 ± 4 [PUMA TO PROVIDE 120Vdc TO 28Vdc CONVERTER TO PROVIDE REQ. POWER INTERFACE[4]
NUMBER OF SAMPLES:	80 [4 VDA TRAYS], 6 (COS), OTHER - TBD
MONITORING CAPABILITY:	FRONT PANEL, TEMPERATURE, SAMPLE RATE - 1 PER 5 MINUTES FOR 30 DAYS
SOLUTION CONCENTRATION -	APPARATUS FUNCTION
MONITORING:	NO
CONTROL:	NO
TEMPERATURE -	
MONITORING:	< 10 TEMP. SENSORS, PROGRAMMABLE BATTERY OPERATED LOGGER
CONTROL:	TEU - FAN FORCED CONVECTION
RANGE -°C:	1 - 40 (POTENTIAL FOR EXPANSION)[1]
ACCURACY - °C:	± 0.1 - MUST BE INCREASED TO ± 0.05
RAMP:	YES [MAGNITUDE - NA], STABILIZATION TIME - NA, RAMP RATE - NA
CONTROL CAPABILITY:	PROGRAMMABLE TEMP. PROFILE AND SETPOINTS, TEU FAN FORCED CONV. TEMP.
CDMS REQUIREMENTS:	INCLUDED IN FACILITY RQMTS
COST:	$1,260,000

Data Source:
1. Space Industries International Inc. brochure.
2. Teledyne Brown Engineering APCGF Science Package.
3. Teledyne Brown CODR package April, 1992
4. Payload Utilization Mgmt. Activities package, Boeing, Jan. 1992

Figure 7.3-5 Existing Experiment Hardware-TES

ADVANCED PROTEIN CRYSTALLIZATION FACILITY
SUMMARY DESCRIPTION

- APCF -

DEVELOPER:	DORNIER GmbH
DESCRIPTION:	FREE INTERFACE, VAPOR DIFF., DIALYSIS; SPACE OF ONE MID-DECK LOCKER
DIMENSIONS [DxWxH] - CM:	INTERIOR - 36.1 x 16 x 18.2 EXTERIOR - 40.4 x 23.9 x 50
MASS -Kg :	EMPTY - 22.7 PAYLOAD - NA
PROTEIN VOLUME - µl:	20 - 450
POWER REQUIREMENTS - WATTS:	65
VOLTAGE - VOLTS:	28 ± 4
NUMBER OF SAMPLES:	48
MONITORING CAPABILITY:	12 CELLS, B&W CCD CAMERA, VIDEO SAMPLE RATE - NA
SOLUTION CONCENTRATION -	
MONITORING:	NA
CONTROL:	NA
TEMPERATURE -	
MONITORING:	N/A
CONTROL:	PRESET
RANGE - °C:	4 - 40
ACCURACY - °C:	NA
RAMP:	NO
CONTROL CAPABILITY:	TEMPERATURE SETTING - FIXED
CDMS REQUIREMENTS:	NA
COSTS:	NA

Data Source::
Teledyne Brown Engineering APCGF Science Package, Jan., 1992

Figure 7.3-6 Existing Experiment Hardware-APCGF

NETHERLANDS PROTEIN CRYSTALLIZATION FACILITY SUMMARY DESCRIPTION

- NPCF -

DEVELOPER:	COMPRIMO, FOKKER, CCM
DESCRIPTION:	VAPOR DIFF., LIQ.-LIQ. DIFF., DIALYSIS; SPACE OF ONE MID-DECK LOCKER
DIMENSIONS [DIA .x H] -CM	50 x 15 [CYLINDRICAL]
MASS Kg:	NA
PROTEIN VOLUME - µl:	NA
POWER REQUIREMENTS - WATTS:	NA
VOLTAGE - VOLTS:	NA
NUMBER OF SAMPLES	400
MONITORING CAPABILITY:	80 CELLS, B&W CCD CAMERA, REAL-TIME RECORDED, SAMPLE RATE - NA
SOLUTION CONCENTRATION -	
MONITORING:	N/A
CONTROL:	N/A
TEMPERATURE -	
MONITORING:	NA
CONTROL::	NA
RANGE - ◦C:	NA
ACCURACY: -◦C:	NA
RAMP:	NA
CONTROL CAPABILITY:	CCD CAMERA ROTATES [PREPLANED?]
CDMS REQUIREMENTS:	NA
COST:	NA

Data Source:
1. Comprimo Consulting Services, Centrum voor Construcie en Mechatronica, Fokker Space & Systems brochure,
2.. Teledyne Brown Engineering APCGF Science Package, Jan., 1992

Figure 7.3-7 Existing Experiment Hardware-NPCF

apparatus must fit in the enclosure, which must fit in the facility etc. It should be noted that the apparatuses and enclosure developed during the AO-2/NRA-3 era will not physically fit the enclosure and core facility developed under AO-1/NRA-2. This was done intentionally to allow the later designs to be as physically large as practical to accomodate larger experiments. The impacts of this assumed guideline are discussed in Section 11.0.

The methods used to estimate total apparatus mass are based on the assumption that if the number of cells per apparatus is doubled (or halved) the resulting mass estimates will also double (or halve) without serious loss of accuracy. The assumption was also used that the overall experiment density (kg per cc) remains approximately constant for the experiment sizes evaluated. It was also assumed that the apparatus power requirements (excluding the enclosure requirements for thermal control) will also double or halve if the number of samples per monitor (or per solution concentration control device) remains constant. It was also assumed that the total mass and power requirements always increase with increased experiment capability. The rate of increase however will be lower for the more demanding requirements.

Figure 7.3-8 is a summary description identifying the basic parameters and resulting mass and power requirements of all the experiment apparatuses defined in the study The mass and power requirements were estimated for the varied conditions selected for each of the five basic parameters. These conditions were presented on Figures 7.2-1 through 7.2-5 and are summarized on 7.3-8 for easy reference. The mass and power estimates made for start and stop control, temperature (control), solution concentration (control), and number of samples have been summed and are listed as total values. This method deemphasises the inherent inaccuracies associated with individual evaluations. These resultant parameter values shown are the end result of the evaluations described herein; they represent the mass and power requirements values for the eleven new apparatuses only. The two new enclosures and two new or improved CORE facilities and the ARACK designs were treated separately and the resulting requirements are shown on Figures 7.3-9 and 7.3-10 respectively. As shown on Figure 7.3-8, the apparatus total mass requirements for the conditions evaluated, span the range of 13 kg to 27 kg; and the total power requirement spans 34w to 395w.

The power and mass requirements for the two new enclosures were calculated in much the same manner described for the apparatuses except, the enclosure function evaluated is temperature control and maintenance. The maximum estimated enclosure power requirement during the era AO-1/NRA-2, was 120w for the apparatus 3-enclosure 1 combination. This value is therefore the design point for new enclosure 1 (E-1, Figure 7.3-9), even though that requirement is not necessary for the other three configurations in that era. Figure 7.3-9 also presents a power and mass budget summary for all configurations considered, except for the one which includes the ARACK which is shown in Figure 7.3-10. Figures 7.3-9 and 7.3-10 were constructed by taking the power and mass availability limits [39] as starting values and subtracting the estimated experiment

design requirements for each apparatus and enclosure from these limits on a case by case basis, to determine whether or not the calculated requirements had exceeded the available resources.

For example, the same Apparatus 3-Enclosure 1 configuration has 1600w available to the experiment after deducting the 1400w core facility requirement from the total. Further deductions of 360w for three enclosures and 315w for three apparatuses, leaves a margin of + 925w theoretically available. Applying the same approach to the mass calculations, this same configuration has 305kg available to the experiment after deducting the core facility requirement of 395kg from the per-rack launch limit [39] of 700kg. Further deductions of 123kg for three enclosures and 54kg for three apparatuses, leaves a balance of 128kg theoretically available. All of the other selected configurations show a positive balance for both power and mass for all configurations. The conclusion can be drawn from this data that the most demanding configuration requirements generated in this study could be increased by as much as 200% and 40% for mass and power respectively without exceeding the documented resource limits. Figure 7.3-10 contains data for the ARACK configuration (core facility + auxiliary rack for program option 3, Figure 6.0-1) in the same format as Figure 7.3-9. Figure 7.3-10 also contains a repeat of the four AO-2/NRA-3 era configurations for easy comparison to the ARACK configuration.

The data shown indicates a substantial increase in capability with the addition of the ARACK: more than twice the total number of experiments. The most demanding experiment requirements (App-8/Enc-2 configuration) were used to calculate the C-2 + ARACK values.

As additional supplemental verification of the trends and/or completeness of the experiment apparatus "designs" created in this study, several more graphs were plotted and are presented here for inspection, Figures 7.3-11 through 7.3-16. The video monitoring system mass and power requirements as a function of number of samples monitored are shown on Figures 7.3-11 and 7.3-12 respectively. The numbers shown with each data point identifies the apparatus number represented by that design point. The COS (Crystal Observation System) apparatus (Ref. Figure 7.3-2) is also shown for reference since it was used as a reference data source. Figures 7.3-13 and 7.3-14 present the control system mass and power as a function of the total number of samples. Again, the COS apparatus requirement value is shown for comparison. Figures 7.3-15 and 7.3-16 show the total apparatus mass and power requirements also as a function of total number of samples. The COS is again shown for reference on both of these figures and the VDA (Vapor Diffusion Apparatus Ref. Figure 7.3-1) is also shown on Figure 7.3-15 for reference.

These graphs were made using number-of-samples as the independent axis since that parameter was used to some degree in all of the experiment evaluations and designs, and is a documented and readily available parameter for each. Number-of-samples, in itself, is not a very sensitive parameter, but

BASIC PARAMETER VARIATIONS AND RESULTANT IMPACTS
APPARATUS
SUMMARY DESCRIPTION

	NRA-1			AO-1/NRA-2				AO-2/NRA-3			
HARDWARE:	CONFIGURATION										
APPARATUS-	1N	2N	3N	1	2	3	4	5	6	7	8
ENCLOSURE-	TES	TES	TES	E-1	E-1	E-1	E-1	E-2	E-2	E-2	E-2
FACILITY-	-T	-T	-T	C-1	C-1	C-1	C-1	C-2	C-2	C-2	C-2
BASIC PARAMETERS											
MONITORING: # SAMPLES	20R	30R	200R	50RT	50RT	75RT	500RT	100RT	100RT	150RT	1500RT
CONTROL: START	AP	AP	AP	AP	AP	AP	AP	RT	RT	RT	RT
STOP	AP	AP	AP	AP	AP	RT	AP	RT	RT	AP	AP
TEMP RAMP	-	AP	-	AP	AP	RT	AP	RT	RT	AP	RT
VARY SOL CONC	-	AP	-	AP	AP	RT	-	RT	RT	AP	RT 2 STG
TEMP: RANGE-°C	1-40	1-40	1-40	1-40	1-60	1-40	1-60	1-60	1-60	1-60	1-60
ACCURACY-±°C	0.05	0.05	0.05	0.05	0.05	0.02	0.05	0.02	0.05	0.05	0.05
RAMP	-	AP	-	AP	AP	RT	AP	RT	RT	AP	RT
SOL CONC: CONTROL	PS	V-AP	PS	V-AP	V-AP	V-RT	PS	V-RT	V-RT	V-AP	V-RT 2 STG
NO. OF SAMPLES: TOTAL	200	100	200	500	200	750	500	1000	500	750	1500
RESULTANT PARAMETERS											
MASS - Kg TOTAL	13	15	14	17	17	18	17	20	20	18	27
POWER-W TOTAL	34	40	90	85	80	105	245	115	115	140	395

R-	RECORDED	TEMP-	TEMPERATURE	2 STG-	TWO VARIATIONS	C-1-	NEW CORE FACILITY-1
RT-	REAL-TIME	SOL CONC-	SOLUTION CONCENTRATION	TES-	THERMAL ENCLOSURE SYSTEM	C-2-	NEW CORE FACILITY-2
AP-	AUTO/PREPLANED	V-AP-	VARY AUTO/PREPLANED	E-1-	NEW THERMAL ENCLOSURE -1	NRA-1-	NRA-1 TIME ERA
PS-	PRESET	V-RT-	VARY REAL-TIME	E-2-	NEW THERMAL ENCLOSURE -2	AO-1/NRA-2-	AO-1/NRA-2 TIME ERA
						AO-2/NRA-3-	AO-1/NRA-2 TIME ERA

Figure 7.3-8 Basic Parameter Variations and Resultant Impacts

POWER AND MASS BUDGET
APPARATUS, ENCLOSURE AND FACILITY
SUMMARY DESCRIPTION

	NRA-1			AO-1/NRA-2				AO-2/NRA-3			
HARDWARE:	CONFIGURATION										
APPARATUS-ENCLOSURE-FACILITY	1N TES -T	2N TES -T	3N TES -T	1 E-1 C-1	2 E-1 C-1	3 E-1 C-1	4 E-1 C-1	5 E-2 C-2	6 E-2 C-2	7 E-2 C-2	8 E-2 C-2
POWER-WATTS											
CAPABILITY:[1]	3000	3000	3000	3000	3000	3000	3000	6000	6000	6000	6000
CORE + COMP REQM'T	-1400	-1400	-1400	-1400	-1400	-1400	-1400	-1400	-1400	-1400	-1400
AVAILABLE TO EXP'S	1600	1600	1600	1600	1600	1600	1600	4600	4600	4600	4600
ENC REQM'T [EACH]	80	90	80	105	95	120	100	135	120	115	145
TOTAL [x3]	-240	-270	-240	-315	-285	-360	-300	-405	-360	-345	-435
APP REQM'T [EACH]	35	40	90	85	80	105	245	115	115	140	395
TOTAL [x3]	-105	-120	-270	-255	-240	-315	-735	-345	-345	-420	-1185
BUDGET [+/-] TOTAL:	**+1255**	**+1210**	**+1090**	**+1030**	**+1075**	**+925**	**+565**	**+3850**	**+3895**	**+3835**	**+2980**
MASS-Kg											
LAUNCH LIMIT:[1]	700	700	700	700	700	700	700	700	700	700	700
CORE + COMP REQM'T	-395	-395	-395	-395	-395	-395	-395	-395	-395	-395	-395
AVAILABLE TO EXP's	305	305	305	305	305	305	305	305	305	305	305
ENC REQM'T - EACH	32	32	32	41	41	41	41	48	48	48	48
TOTAL [x3]	-96	-96	-96	-123	-123	-123	-123	-144	-144	-144	-144
APP REQM'T - EACH	13	15	14	17	17	18	17	20	20	18	27
TOTAL [x3]	-39	-45	-42	-51	-51	-54	-51	-60	-60	-54	-81
BUDGET [+/-] TOTAL:	**+170**	**+164**	**+167**	**+131**	**+131**	**+128**	**+131**	**+101**	**+101**	**+107**	**+80**

1. TELEDYNE BROWN ENGINEERING, APCGF CODR DATA PACKAGE APRIL, 1992

Figure 7.3-9 Power and Mass Budget

POWER AND MASS BUDGET
APPARATUS, ENCLOSURE, CORE FACILITY + ARACK
SUMMARY DESCRIPTION

HARDWARE:	AO-2/NRA-3 CONFIGURATION				
APPARATUS-	5	6	7	8	8
ENCLOSURE-	E-2	E-2	E-2	E-2	E-2
FACILITY-	C-2	C-2	C-2	C-2	C-2 + ARACK
POWER-WATTS					
CAPABILITY-WATTS:[1]	6000	6000	6000	6000	6000
CORE + COMP REQM'T	-1400	-1400	-1400	-1400	[1400+490[2]]=1890
AVAILABLE TO EXP'S	4600	4600	4600	4600	4110
ENC REQM'T [EACH]	135	120	115	145	[HIGHEST]145
TOTAL [x3]	-405	-360	-345	-435	[x7] -1015
APP REQM'T [EACH]	115	115	140	395	[HIGHEST]395
TOTAL [x3]	-345	-345	-420	-1185	[x7] -2765
BUDGET [+/-] - TOTAL	**+3850**	**+3895**	**+3835**	**+2980**	**+330**
MASS-Kg					
LAUNCH LIMIT[1] Kg:	700	700	700	700	700+700=1400
CORE + COMP REQM'T	-395	-395	-395	-395	-[395+349[3]]=744
AVAILABLE TO EXP's	305	305	305	305	[305+351]=656
ENC REQM'T - EACH	48	48	48	48	48
TOTAL [x3]	-144	-144	-144	-144	[x7] = -336
APP REQM'T - EACH	20	20	18	27	[HIGHEST] 27
TOTAL [x3]	-60	-60	-54	-81	[x7] = -189
BUDGET [+/-] - TOTAL	**+101**	**+101**	**+107**	**+80**	**+131**

1. TELEDYNE BROWN ENGINEERING, APCGF CODR PACKAGE APRIL, 1992
2. VALUE BASED ON 65% REQUIREMENT SHARING WITH CORE FACILITY WILL (ARACK MUST USE 35% OF NORMAL CORE ALLOTMENT)
3. ESTIMATED BASED ON EMPTY FURNACE RACK, SSFF, RDR, MAY 1992

Figure 7.3-10 Power and Mass Budget (including ARACK)

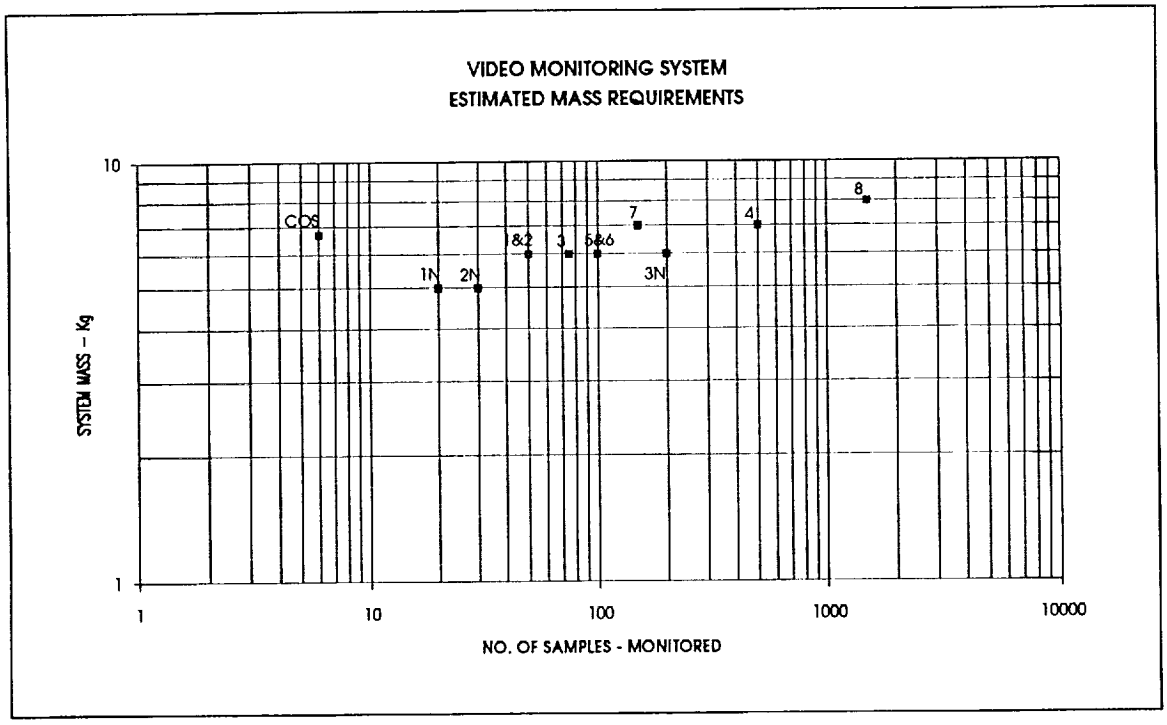


Figure 7.3-11 Video Monitoring System Mass Estimates

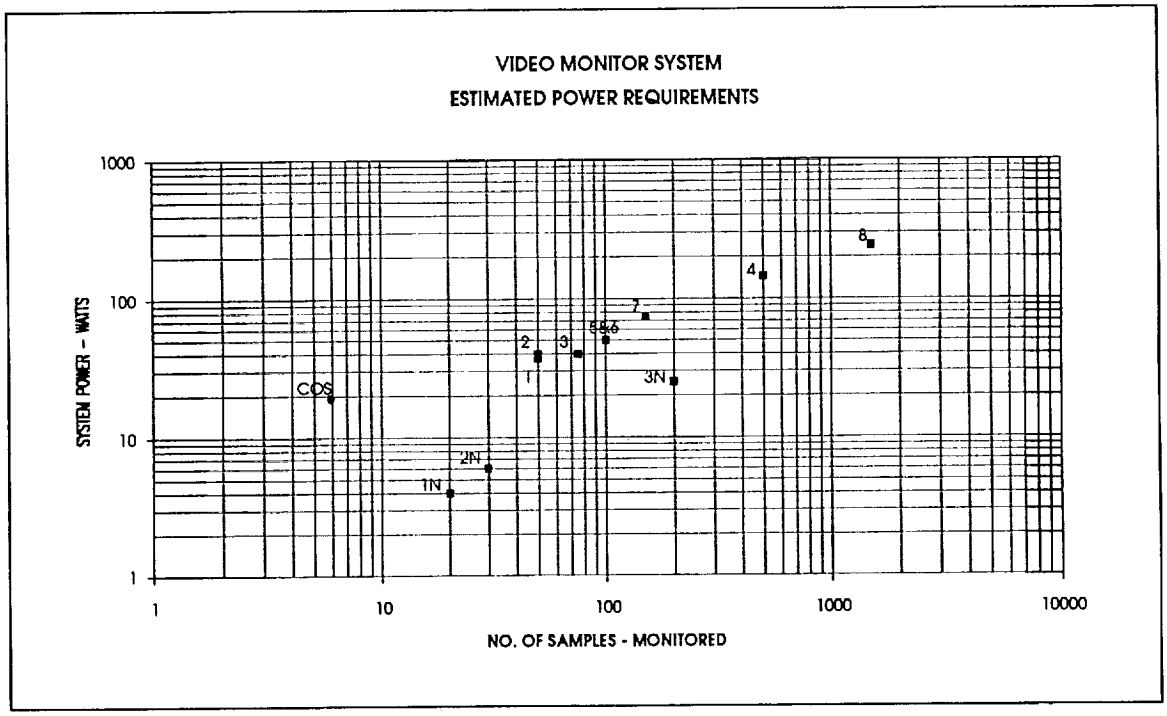


Figure 7.3-12 Video Monitoring System Power Estimates

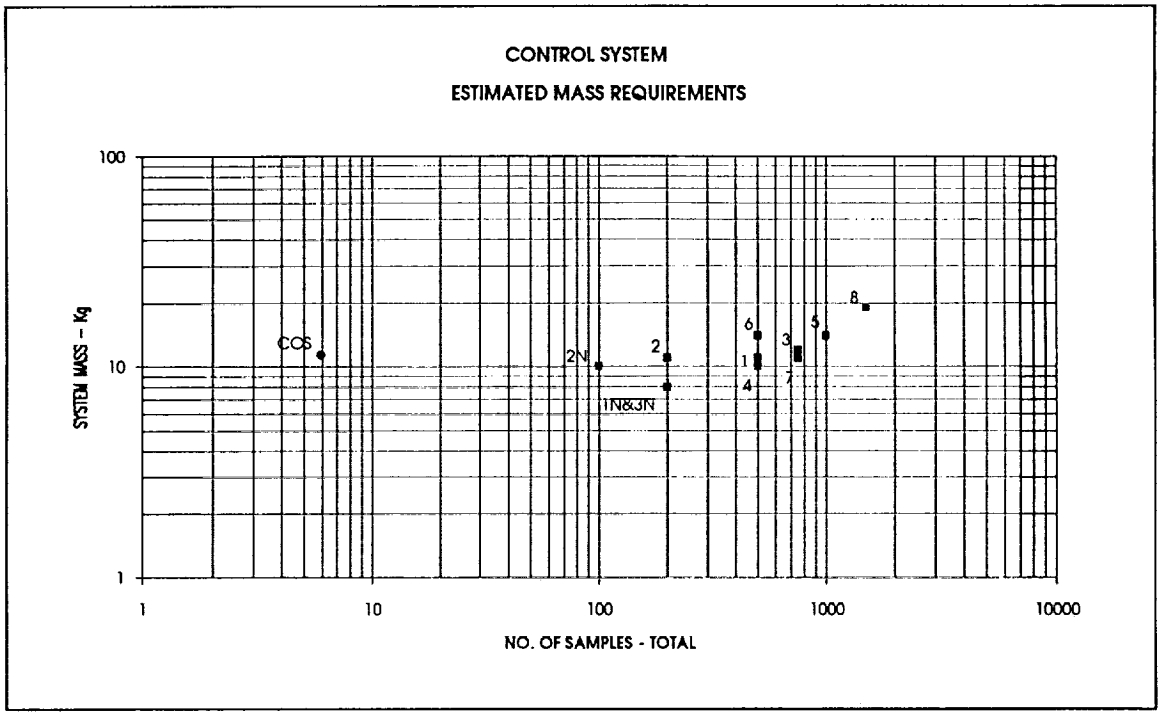


Figure 7.3-13 Control System Mass Estimates

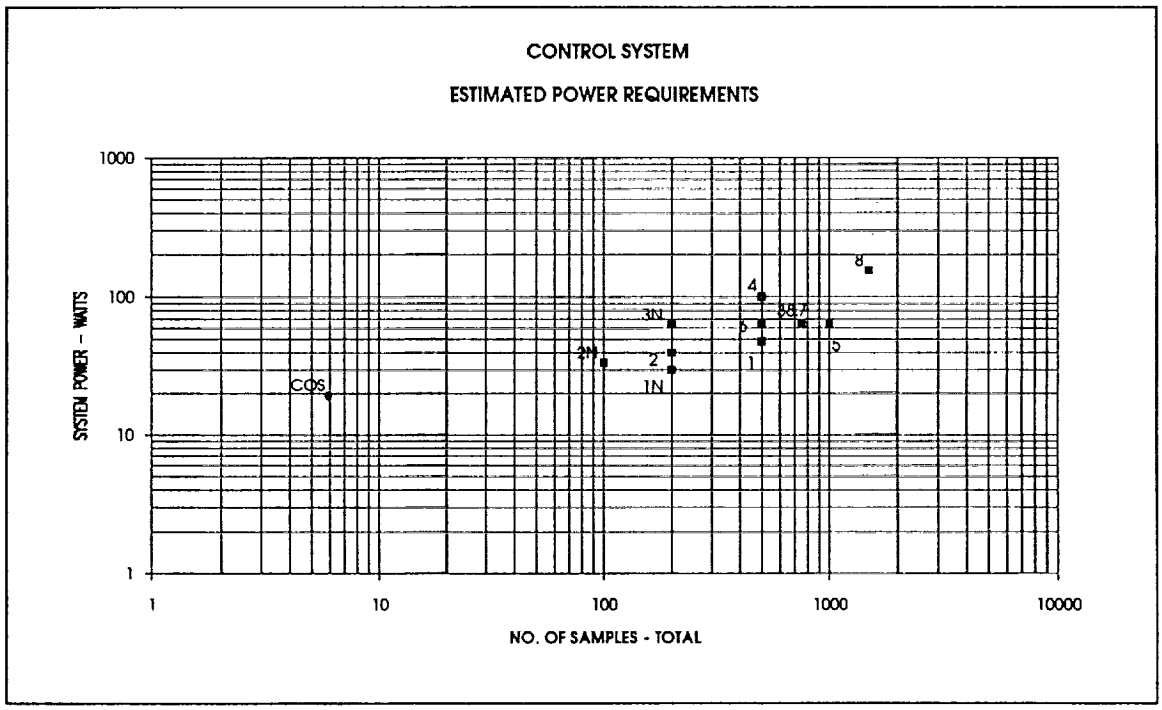


Figure 7.3-14 Control System Power Estimates

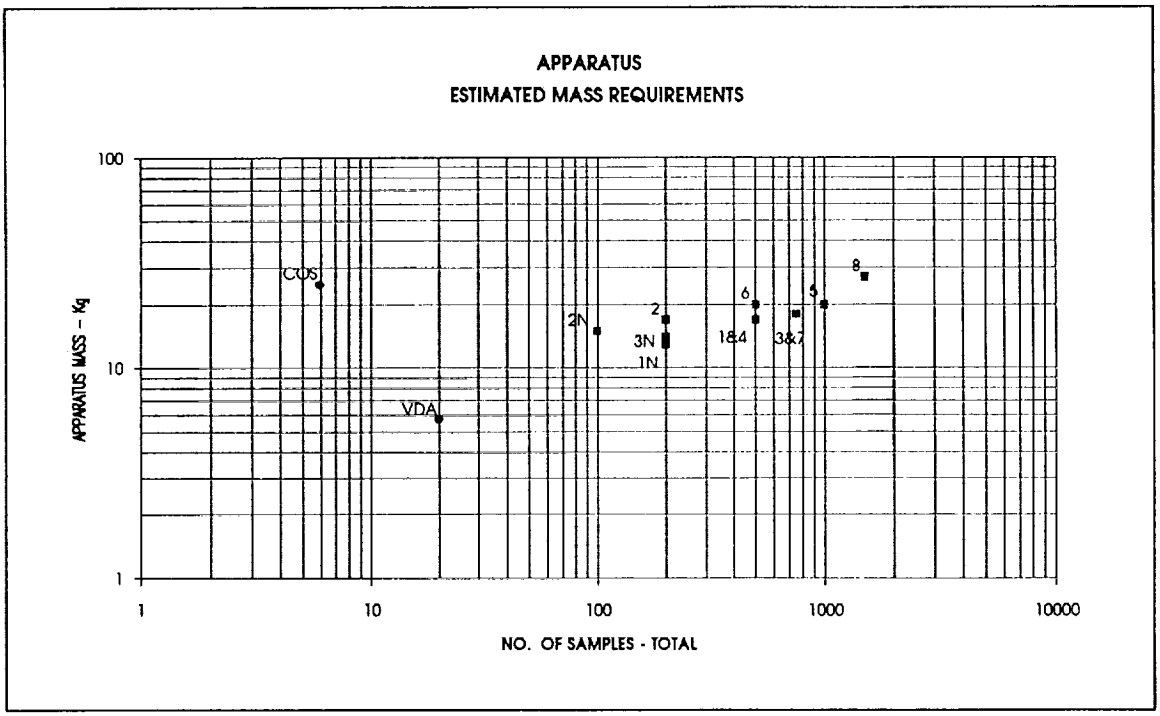


Figure 7.3-15 Apparatus Mass Estimates

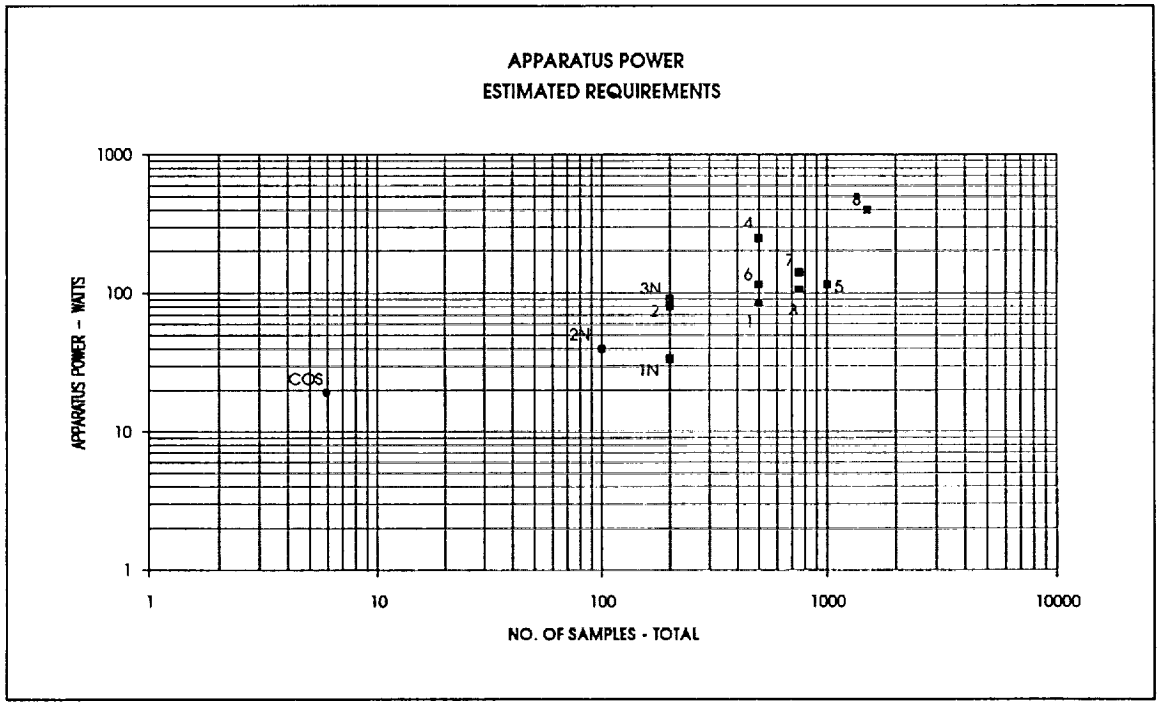


Figure 7.3-16 Apparatus Power Estimates

when coupled with some of the other parameters e.g., real-time monitoring for example, the power requirements increase significantly for the larger number of samples configurations.

When compared with the COS and VDA existing data, and looking at the general trend or slope, the experiment configuration designs generated and evaluated in this study are credible. Since the data used for these evaluations are the result of extrapolation and judgement based on a relatively small amount of data, and the scope of each design was limited to specific requirements, the confidence level in any particular design value must be accordingly applied. However, it can be seen from Figures 7.3-9 and -10 that from 330 watts to more than 3800 watts of power; and from 80kg to 170kg of mass are still available for experiment use. If future designs or further refinement of these designs require additional mass or power, our evaluations indicate it is readily available.

7.4 Complexity

The relative experiment configuration complexities were estimated and are shown on Figure 7.4-1. Estimates were made for each basic parameter as a function of each configuration evaluated. A detailed description of the method used to rank each item is given in the figure legend. The assigned values used to calculate the relative complexity ranking are subjective and qualitative. The basis for this subjective reasoning was accumulated through the many iterations required during experiment design and impact evaluations. Several conclusions are apparent based on the data presented on Figure 7.4-1 and will be discussed in Section 11.0. However, our calculations indicate one major conclusion is that real-time monitoring, and temperature control and ramping are two of the more "costly" modes-of-operation.

7.5 Experiment Definition Using Modified Parameters

Figures 7.5-1 through 7.5-17 are summary descriptions of the experiment hardware designed and/or defined and evaluated in this study.

Figures 7.5-1 through 7.5-11 are summary descriptions of each of the eleven new experiment apparatuses which were defined; subjected to selected modifications of each of the five basic parameters; and then evaluated for scientific impact. The enclosure summary descriptions of the three designs evaluated: 1-TES (existing); 2-Enc-1(new); and 3-Enc-2 (new) are presented on Figures 7.3-5, 7.5-12 and 7.5-13 respectively. The TES was used with the APCG-T facility during transition (Figures 6.0-1 and 6.0-2). Enc's 1 & 2 were used for the MTC and PMC program phases, (also Figures 6.0-1 and 6.0-2). The new or improved core facility summary descriptions are presented on Figures 7.5-14, 7.5-15, and 7.5-16. The new auxiliary RACK description is shown on Figure 7.5-17.

The above figures individually describe the experiment capabilities and requirements. Examination of the data on Figures 7.3-8 through 7.3-10 provides scientific impact cause and effect traceability for each parameter modification for each experiment configuration. The program scenarios generically developed in section 6.0, and scientifically evaluated earlier in this section, can now be evaluated programmatically. Further program impact evaluations, both scientific and programmatic may be accomplished using the design data generated in this study. Additional hardware and schedule reconfiguration may be selected and evaluated as desired.

COMPLEXITY
ESTIMATED NORMALIZED EXPERIMENT RANKING
SUMMARY DESCRIPTION

	NRA-1			AO-1/NRA-2				AO-2/NRA-3			
HARDWARE:	CONFIGURATION										
APPARATUS-	1N	2N	3N	1	2	3	4	5	6	7	8
ENCLOSURE-	TES	TES	TES	E-1	E-1	E-1	E-1	E-2	E-2	E-2	E-2
FACILITY-	-T	-T	-T	C-1	C-1	C-1	C-1	C-2	C-2	C-2	C-2
BASIC PARAMETER											
MONITORING: VIDEO	1	1.8	5.8	3.6	3.6	4.6	9.4	5.2	5.2	6.2	12.0
CONTROL: START/STOP	2	2	2	2	2	2.2	2	2.4	2.4	2.2	2.2
TEMP: CONTROL	2.4	3.2	2.4	4.5	4.2	7.4	5.3	9.4	5.6	6.1	9.3
SOL CONC: CONTROL	0	1	0	1	1	1.2	0	1.2	1.2	1	1.4
NO. OF SAMPLES: TOTAL	3.2	1	3.2	4.0	3.2	4.4	4.0	4.6	4.0	4.4	5
NUMERICAL RATING	8.6	9.1	13.4	15.1	14.0	19.8	20.7	22.8	18.4	19.9	29.9
COMPLEXITY [NORMALIZED]	**10**	**12**	**31**	**38**	**33**	**58**	**62**	**70**	**52**	**58**	**100**

LEGEND:

-INITIAL

MONITORING:	RATED 1 TO 10 AS FUNCTION OF CELLS MONITORED; + 20% FOR R-T
CONTROL:	RATED 1 FOR EACH COMMAND; + 20% FOR R-T
TEMPERATURE:	RATED 1 FOR SMALLER RANGE; 1.5 FOR LARGER RANGE; RATED 1 FOR LESS DEMANDING ACCURACY; 2 FOR MOST DEMANDING; RATED 0 FOR NO RAMP; 1 FOR PREPLANED RAMP + 20 % FOR R-T; SUMMATION OF ABOVE MULTIPLIED BY FUNCTION OF NUMBER OF CELLS [1 < 2.5]
SOLUTION CONCENTRATION:	RATED 0 FOR NO VARIATION; 1 FOR PREPLANED VARIATION + 20% FOR R-T
NUMBER OF SAMPLES:	RATED 1 TO 5 AS FUNCTION OF TOTAL CELLS

-NORMALIZATION

OVERALL:	RANKED LEAST TO MOST COMPLEX - 10 TO 100

Figure 7.4-1 Complexity

APPARATUS
SUMMARY DESCRIPTION

- APP -1_N -

DEVELOPER:	TBD
DESCRIPTION:	VAPOR DIFFUSION - IMPROVED COS CONCEPT - OTHER (TBD)
DIMENSIONS [1] [D x W x H] - CM:	33 x 22.9 x 16.5
MASS - Kg:	12.7
PROTEIN VOLUME - µl:	10 to 200
POWER REQUIREMENTS - WATTS:	35
VOLTAGE - VOLTS:	TBD - 28dc & 120dc AVAILABLE
NUMBER OF SAMPLES:	200 TOTAL
MONITORING CAPABILITY:	20 CELLS, VIDEO, RECORDED
SOLUTION CONCENTRATION -	
MONITORING:	NO
CONTROL:	PRESET
TEMPERATURE REQUIREMENTS:	ENCLOSURE FUNCTION
MONITORING:	RECORDED
CONTROL:	PRESET (LEVEL - TBD)
RANGE - °C:	1 - 40, AVAILABLE ,PRESET AT TBD
ACCURACY - °C:	± 0.05
RAMP:	NO
CONTROL CAPABILITY:	START & STOP, PREPLANNED
COMPLEXITY RATING:	10
COST:	$598,000

1. TES Limitation allowing 1.3 cm clearances.

Figure 7.5-1 Apparatus 1_N

APPARATUS
SUMMARY DESCRIPTION

- APP-2_N -

DEVELOPER:	TBD
DESCRIPTION:	TBD
DIMENSIONS [D x W x H] - CM:	33 x 22.9 x 16.5
MASS - Kg:	14.5
PROTEIN VOLUME - µl:	10 TO 200
POWER REQUIREMENTS - WATTS:	40
VOLTAGE - VOLTS:	TBD - 28dc OR 120dc AVAILABLE
NUMBER OF SAMPLES:	200 TOTAL
MONITORING CAPABILITY:	30 CELLS, VIDEO, RECORDED
SOLUTION CONCENTRATION -	
MONITORING:	NO
CONTROL	VARY - PREPLANNED
TEMPERATURE REQUIREMENTS	ENCLOSURE FUNCTION
MONITORING:	RECORDED
CONTROL:	PREPLANNED RAMP
RANGE - °C:	1 TO 40 AVAILABLE, SET POINT TBD
ACCURACY - °C:	± 0.05
RAMP:	YES - PREPLANNED (MAGNITUDE TBD)
CONTROL CAPABILITY:	START/STOP/VARY TEMP./VARY SOL. CONC, - PREPLANNED
COMPLEXITY RATING:	12
COST:	$649,000

1- TES limitation allowing 1.3cm clearances.

Apparatus 2-

Figure 7.5-2 Apparatus 2_N

APPARATUS
SUMMARY DESCRIPTION

- APP - 3_N -

DEVELOPER:	TBD
DESCRIPTION:	TBD
DIMENSIONS [D x W x H] - CM:	33 x 22.9 x 16.5
MASS -Kg:	14
PROTEIN VOLUME - µl:	10 TO 200
POWER REQUIREMENTS - WATTS:	90
VOLTAGE - VOLTS:	TBD - 28dc & 120dc AVAILABLE
NUMBER OF SAMPLES:	200 TOTAL
MONITORING CAPABILITY:	200 CELLS, VIDEO, RECORDED
SOLUTION CONCENTRATION -	
MONITORING:	NO
CONTROL:	PRESET
TEMPERATURE REQUIREMENTS:	ENCLOSURE FUNCTION
MONITORING:	RECORDED
CONTROL:	PRESET (LEVEL TBD)
RANGE - °C:	1 TO 40 AVAILABLE, SETPOINT TBD
ACCURACY - °C:	± 0.05
RAMP:	NO
CONTROL CAPABILITY:	START/STOP - PREPLANNED
COMPLEXITY RATING:	31
COST:	$776,000

1. TES limitation allowing 1.3 cm clearances

Figure 7.5-3 Apparatus 3_N

APPARATUS
SUMMARY DESCRIPTION

- APP-1 -

DEVELOPER:	TBD
DESCRIPTION:	TBD
DIMENSIONS [D x W x H] - CM:	38.1 x 27.9 x 27.9
MASS - Kg:	16.8
PROTEIN VOLUME - µl:	25 TO 500
POWER REQUIREMENTS - WATTS:	85
VOLTAGE - VOLTS:	TBD 28DC & 120dc AVAILABLE
NUMBER OF SAMPLES:	500 TOTAL
MONITORING CAPABILITY:	50 CELLS, VIDEO, REAL-TIME, RECORDED,SAMPLE RATE TBD
SOLUTION CONCENTRATION -	
MONITORING:	NO
CONTROL:	ONE CHANGE, PREPLANNED
TEMPERATURE REQUIREMENTS:	ENCLOSURE FUNCTION
MONITORING:	RECORDED
CONTROL:	PREPLANNED, RAMP
RANGE - °C:	1 - 40 AVAILABLE, SET POINT TBD
ACCURACY - °C:	± 0.05
RAMP:	YES - PREPLANED (MAGNITUDE TBD)
CONTROL CAPABILITY:	START/STOP/RAMP
	TEMPERATURE/VARY SOL, CONC. PREPLANNED
COMPLEXITY RATING:	38
COST:	$717,600

Figure 7.5-4 Apparatus 1

APPARATUS
SUMMARY DESCRIPTION

- APP-2 -

DEVELOPER:	TBD
DESCRIPTION:	TBD
DIMENSIONS [D x W x H] - CM:	38.1 x 27.9 x 27.9
MASS - Kg:	18.1
PROTEIN VOLUME - µl:	10 TO 200
POWER REQUIREMENTS - WATTS:	105
VOLTAGE - VOLTS:	TBD - 28dc & 120dc AVAILABLE
NUMBER OF SAMPLES:	200 TOTAL
MONITORING CAPABILITY:	50 CELLS, VIDEO, REAL-TIME, RECORDED SAMPLE RATE TBD
SOLUTION CONCENTRATION -	
MONITORING:	NO
CON TROL:	ONE CHANGE - PREPLANNED
TEMPERATURE REQUIREMENTS	ENCLOSURE FUNCTION
MONITORING:	RECORDED
CONTROL:	RAMP - PREPLANNED
RANGE - °C:	1 TO 60 AVAILABLE, SETPOINT TBD
ACCURACY - °C:	± 0.05
RAMP:	YES - PREPLANNED (MAGNITUDE TBD)
CONTROL CAPABILITY:	START/STOP/RAMP TEMP./VARY SOL. CONC. PREPLANED
COMPLEXITY RATING:	33
COST:	$778,800

Figure 7.5-5 Apparatus 2

APPARATUS
SUMMARY DESCRIPTION

- APP-3 -

DEVELOPER:	TBD
DESCRIPTION:	TBD
DIMENSIONS [D x W x H] - CM:	38.1 x 27.9 x 27.9
MASS - Kg:	18.1
PROTEIN VOLUME - µl:	40 TO 750
POWER REQUIREMENTS - WATTS:	105
VOLTAGE - VOLTS:	TBD - 28dc & 120dc AVAILABLE
NUMBER OF SAMPLES:	750 TOTAL
MONITORING CAPABILITY:	75 CELLS, VIDEO, REAL-TIME, RECORDED SAMPLE RATE TBD
SOLUTION CONCENTRATION -	
MONITORING:	NO
CONTROL:	ONE CHANGE, REAL-TIME
TEMPERATURE REQUIREMENTS:	ENCLOSURE FUNCTION
MONITORING:	RECORDED
CONTROL:	REAL-TIME RAMP
RANGE - °C:	1 TO 40 AVAILABLE, SETPOINT TBD
ACCURACY - °C:	± 0.02
RAMP:	YES - REAL-TIME (MAGNITUDE TBD)
CONTROL CAPABILITY:	START-PREPLANNED, STOP/ RAMP TEMPERATURE/VARY SOL. CONC. - REAL TIME
COMPLEXITY RATING:	58
COST:	$845,219

Figure 7.5-6 Apparatus 3

APPARATUS
SUMMARY DESCRIPTION

- APP-4 -

DEVELOPER:	TBD
DESCRIPTION:	TBD
DIMENSIONS [D x W x H] - CM:	38.1 x 27.9 x 27.9
MASS - Kg:	16.8
PROTEIN VOLUME - µl:	25 TO 500
POWER REQUIREMENTS - WATTS:	245
VOLTAGE - VOLTS:	TBD - 28dc & 120dc AVAILABLE
NUMBER OF SAMPLES:	500 TOTAL
MONITORING CAPABILITY:	500 CELLS - REAL-TIME, RECORDED SAMPLE RATE TBD
SOLUTION CONCENTRATION	
MONITORING:	NO
CONTROL:	PRESET
TEMPERATURE REQUIREMENTS:	ENCLOSURE FUNCTION
MONITORING:	RECORDED
CONTROL:	RAMP - PREPLANNED
RANGE - °C:	1 TO 60 AVAILABLE, SET POINT TBD
ACCURACY -°C:	± 0.05
RAMP:	YES - PREPLANED MAGNITUDE TBD
CONTROL CAPABILITY:	START/STOP/VARY TEMP.- PREPLANNED
COMPLEXITY RATING:	62
COST:	$917,303

Figure 7.5-7 Apparatus 4

APPARATUS
SUMMARY DESCRIPTION

- APP-5 -

DEVELOPER:	TBD
DESCRIPTION:	TBD
DIMENSIONS [DxWxH] - CM:	40.6 x 30.5 x 30.5
MASS - Kg:	20.4
PROTEIN VOLUME - µl:	50 TO 1000
POWER REQUIREMENTS - WATTS:	115
VOLTAGE - VOLTS:	TBD 28dc & 120dc AVAILABLE
NUMBER OF SAMPLES:	1000 TOTAL
MONITORING CAPABILITY:	100 CELLS, VIDEO, REAL-TIME, RECORDED, SAMPLE RATE - TBD
SOLUTION CONCENTRATION -	
MONITORING:	NO
CONTROL:	ONE CHANGE, REAL-TIME
TEMPERATURE REQUIREMENTS -	ENCLOSURE FUNCTION
MONITORING:	RECORDED
CONTROL:	RAMP REAL-TIME,
RANGE - °C:	1 - 60 AVAILABLE, SETPOINT TBD
ACCURACY - °C:	± 0.02
RAMP	REAL-TIME [MAGNITUDE TBD]
CONTROL CAPABILITY:	START/STOP/VARY TEMP; VARY SOL. CONC.; REAL-TIME
COMPLEXITY RATING:	70
COST:	$995,535

Figure 7.5-8 Apparatus 5

APPARATUS
SUMMARY DESCRIPTION

- APP-6 -

DEVELOPER:	TBD
DESCRIPTION:	TBD
DIMENSIONS [D x W x H] - CM:	40.6 x 30.5 x 30.5
MASS - Kg:	20
PROTEIN VOLUME - µl:	25 TO 500
POWER REQUIREMENTS - WATTS:	115
VOLTAGE - VOLTS:	TBD - 28dc & 120dc AVAILABLE
NUMBER OF SAMPLES:	500 TOTAL
MONITORING CAPABILITY:	100 CELLS, VIDEO, REALTIME, RECORDED
SOLUTION CONCENTRATION -	
MONITORING:	NO
CONTROL:	ONE CHANGE
TEMPERATURE REQUIREMENTS	ENCLOSURE FUNCTION
MONITORING:	RECORDED
CONTROL:	RAMP REAL TIME, RECORDED
RANGE - °C:	1 TO 60 AVAILABLE, SET POINT TBD
ACCURACY - °C:	± 0.05
RAMP:	REAL-TIME [MAGNITUDE TBD]
CONTROL CAPABILITY:	START/STOP/VARY TEMP/VARY SOL. CONC; REAL-TIME
COMPLEXITY RATING:	52
COST:	$1,080,438

Figure 7.5-9 Apparatus 6

APPARATUS
SUMMARY DESCRIPTION

- APP-7 -

DEVELOPER:	TBD
DESCRIPTION:	TBD
DIMENSIONS [D x W x H] - CM:	40.6 x 30.5 x 30.5
MASS - Kg:	18.1
PROTEIN VOLUME - µl:	40 TO 750
POWER REQUIREMENTS - WATTS:	140
VOLTAGE - VOLTS:	TBD - 28dc & 120dc AVAILABLE
NUMBER OF SAMPLES:	750 TOTAL
MONITORING CAPABILITY:	150 CELLS - REAL-TIME, RECORDED
SOLUTION CONCENTRATION -	
MONITORING:	NO
CONTROL:	VARY - PREPLANNED
TEMPERATURE REQUIREMENTS -	
MONITORING:	REAL-TIME [SAME AS CELL VIDEO]
CONTROL:	ONE CHANGE - PREPLANNED
RANGE - °C:	1 TO 60
ACCURACY - °C:	± 0.05
RAMP:	PREPLANNED [MAGNITUDE TBD]
CONTROL CAPABILITY:	START - REAL-TIME; STOP/VARY TEMP/VARY SOL. CONC- PREPLANNED
COMPLEXITY RATING:	58
COST:	$1,172,583

Figure 7.5-10 Apparatus 7

APPARATUS
SUMMARY DESCRIPTION

- APP-8 -

DEVELOPER:	TBD
DESCRIPTION:	TBD
DIMENSIONS [D x W x H] - CM:	40.6 x 30.5 x 30.5
MASS - Kg:	27.2
PROTEIN VOLUME - µl:	75 TO 1500
POWER REQUIREMENTS - WATTS:	395
VOLTAGE - VOLTS:	TBD - 28dc & 120DC AVAILABLE
NUMBER OF SAMPLES:	1500 TOTAL
MONITORING CAPABILITY:	1500 CELLS, VIDEO, REAL-TIME RECORDED
SOLUTION CONCENTRATION -	
MONITORING:	NO
CONTROL:	TWO CHANGES - REAL-TIME
TEMPERATURE REQUIREMENTS:	ENCLOSURE FUNCTION
MONITORING:	RECORDED
CONTROL:	RAMP - REAL-TIME
RANGE - °C:	1 TO 60 AVAILABLE, SET POINT TBD
ACCURACY - °C:	± 0.05
RAMP:	REAL-TIME (MAGNITUDE TBD)
CONTROL CAPABILITY:	START/VARY TEMP/VARY SOL.CONT.- REAL-TIME; STOP - PREPLANNED
COMPLEXITY RATING:	100
COST:	$1,272,586

Figure 7.5-11 Apparatus 8

ENCLOSURE - AO-1/NRA-2
SUMMARY DESCRIPTION

- ENC - 1-

DEVELOPER:	TBD
DESCRIPTION:	THERMAL ENCLOSURE
DIMENSIONS [D x W x H] CM	INTERNAL - 45.7 x 38.1 x 45.7 EXTERNAL - 63.5 x 45.1 x 55.9
MASS - Kg:	EMPTY - 41 PAYLOAD - 18[1]
POWER REQUIREMENTS - WATTS:	ENCLOSURE - 120 EXPERIMENT - 85 < 245
VOLTAGE - VOLTS:	TBD - [28dc OR 120dc AVAILABLE]
NUMBER OF SAMPLES:	APPARATUS FUNCTION
MONITORING CAPABILITY:	TEMPERATURE FUNCTIONS PROGRAMMABLE
SOLUTION CONCENTRATION -	APPARATUS FUNCTION
MONITORING:	COMMAND INTERFACE ONLY
CONTROL:	APPARATUS FUNCTION
TEMPERATURE REQUIREMENTS -	
MONITORING:	RECORDED - SAMPLE RATE TBD
CONTROL:	YES - PROGRAMMABLE & REAL TIME
RANGE - °C:	1 TO 60
ACCURACY - °C:	± 0.05 & ± 0.02 (APP - 3 REQM'T)
RAMP:	YES - PREPLANED & REAL TIME [MAGNITUDE TBD]
CONTROL CAPABILITY:	PROGRAMMABLE & REAL TIME TEMPERATURE; SETPOINTS AND RAMP PROFILE - NA
CDMS REQUIREMENTS:	INCLUDED IN FACILITY CDMS
COST:	$1,575,000

1. Evaluation indicates 18 Kg is adequate experiment mass allocation - could be increased to ~60 Kg based on 700 Kg per rack launch limit

Figure 7.5-12 Enclosure 1

ENCLOSURE - AO-2/NRA-3
SUMMARY DESCRIPTION

- ENC-2 -

DEVELOPER:	TBD
DESCRIPTION:	THERMAL ENCLOSURE
DIMENSIONS[1] [DxWxH] - INCHES:	INTERNAL - 48.3 x 35.6 x 38.1 EXTERNAL - 63.5 x 45.1 x 55.9
MASS - Kg	EMPTY - 48 PAYLOAD 27[1]
POWER REQUIREMENTS - WATTS:	ENCLOSURE - 145 EXPERIMENT - 115 < 395
VOLTAGE - VOLTS:	TBD - [28dc OR 120dc AVAILABLE]
NUMBER OF SAMPLES:	APPARATUS FUNCTION
MONITORING CAPABILITY:	TEMPERATURE FUNCTIONS - PROGRAMMABLE
SOLUTION CONCENTRATION -	APPARATUS FUNCTION
MONITORING:	COMMAND INTERFACE ONLY
CONTROL:	APPARATUS FUNCTION
TEMPERATURE REQUIREMENTS -	
MONITORING:	RECORDED - SAMPLE RATE TBD
CONTROL:	YES - PROGRAMMABLE AND REAL TIME
RANGE: - °C:	1 TO 60
ACCURACY: - °C:	± 0.05 & ± 0.02 (APP- 5 - RQM'T)
RAMP:	YES - REPLANNED & REAL-TIME [MAGNITUDE TBD]
CONTROL CAPABILITY:	PROGRAMMABLE AND REAL-TIME TEMPERATURE SETPOINTS AND RAMP PROFILE -NA
CDMS REQUIREMENTS:	INCLUDED IN FACILITY CDMS
COST:	$2,362,500

1. Evaluation indicates 27 kg is adequate experiment mass allocation - could be increased to ~ 60 kg based on 700 kg per rack lauch limit.

Figure 7.5-13 Enclosure 2

FACILITY - TRANSITION
SUMMARY DESCRIPTION

- APCG-T -

DEVELOPER:	THE BOEING COMPANY
DESCRIPTION:	TRANSITION CORE FACILITY
DIMENSIONS [D x W x H] - CM:	ALLOWABLE EXPERIMENT VOLUME: 63.5 x 45 x 56; SPACE FOR THREE EXP's THIS SIZE OR ONE THIS SIZE + ONE WITH DIM. H ~ DOUBLED
MASS[1] - Kg:	CORE FACILITY 395 AVAILABLE FOR EXPERIMENT 306 TOTAL[2] 700
POWER REQUIREMENTS[1] - WATTS:	CORE FACILITY 1400 AVAILABLE TO EXPERIMENT- 1600 TOTAL 3000
VOLTAGE[1]-VOLTS:	TBD 28 dc OR 120 dc AVAIL. TO EXP.'s
NUMBER OF SAMPLES:	TBD - NO FACILITY LIMIT EXCEPT WEIGHT AND POWER - <200 PLANNED
MONITORING CAPABILITY:	TOP LEVEL MONITORING PROVIDED
SOLUTION CONCENTRATION -	APPARATUS FUNCTION
MONITORING:	COMMAND INTERFACE
CONTROL:	COMMAND INTERFACE
TEMPERATURE REQUIREMENTS -	ENCLOSURE FUNCTION
MONITORING:	COMMAND INTERFACE
CONTROL:	COMMAND INTERFACE
CONTROL CAPABILITY:	TOP LEVEL CONTROL PROVIDED,
CDMS SERVICES:	PROVIDES DATA AND PROGRAM STORAGE
DOWNLINK KU BAND-[MBPS]:	VIDEO
DOWNLINK S BAND-[KBPS]:	0.5
UPLINK S BAND-[KBPS]:	1.1
SSF STANDARD DATA PROCESSOR:	MPAC
SSF MULTIPLEXER/DEMULTIPLEXER:	NO
SSF PAYLOAD DATA PROCESSOR:	NO
FDDI PER RACK:	ONE
MIL-STD-1553-B INTERFACE:	ONE
PATCH PANEL TO HIGH RATE DNLNK:	ONE
POWER- WATTS:	680
MASS - Kg	188
COST:	NA

1. Teledyne Brown Engineering, APCGF CODR data package, April, 1992
2. Launch condition per rack limit

Facility - Transition

Figure 7.5-14 Core Facility - Transition

FACILITY - AO-1/NRA-2
SUMMARY DESCRIPTION

- CORE C-1/APCG-T-1-

DEVELOPER:	TBD
DESCRIPTION:	CORE FACILITY
DIMENSIONS [DxWxH] - CM:	ALLOWABLE EXPERIMENT VOLUME- 63.5 x 45 x 56; SPACE FOR THREE EXP.'s THIS SIZE OR ONE THIS SIZE + ONE WITH DIMENSION H~ DOUBLED
MASS[1] - Kg	CORE FACILITY - 395 AVAILABLE TO EXPERIMENT- 306 TOTAL[2] 700
POWER REQUIREMENTS[1] - WATTS:	CORE FACILITY - 1400 AVAILABLE TO EXPERIMENT 1600 TOTAL 3000
VOLTAGE[1] - VOLTS:	28dc & 120dc AVAIL. TO EXPERIMENT
NUMBER OF SAMPLES	TBD NO FACILITY LIMIT EXCEPT WEIGHT & POWER - < 500 PLANNED
MONITORING CAPABILITY	TOP LEVEL MONITORING PROVIDED
SOLUTION CONCENTRATION -	APPARATUS FUNCTION
MONITORING:	COMMAND INTERFACE
CONTROL:	COMMAND INTERFACE
TEMPERATURE REQUIREMENTS	ENCLOSURE FUNCTION
MONITORING:	COMMAND INTERFACE
CONTROL:	COMMAND INTERFACE
CONTROL CAPABILITY:	TOP LEVEL CONTROL PROVIDED
CDMS SERVICES:	PROVIDES DATA AND PROGRAM STORAGE
DOWNLINK KU BAND-[MBPS]:	VIDEO
UPLINK S BAND-[KBPS]:	1.3
SSF MULTIPURPOSE APPL. CONSOLE:	TIMESHARE
MULTIPLEXER/DEMULTIPLEXER:	NO
FDDI PER RACK:	ONE/<10 MBPS
MIL-STD-1553 INTERFACE:	ONE/<700 KBPS
HDDR LINK BANDWIDTH:	ONE/<<43 MBPS
POWER- WATTS:	705
MASS - kg:	195
COST:	$27,761,738

1. Teledyne Brown Engineering CODR data, April, 1992
2. Launch condition per-rack limit.

Figure 7.5-15 Core Facility, C-1/APCG-T-1

FACILITY - AO-2/NRA-3
SUMMARY DESCRIPTION

- CORE C-2/APCG-T-2-

DEVELOPER	TBD	
DESCRIPTION:	CORE FACILITY	
DIMENSIONS [DxWxH] - CM	ALLOWABLE EXPERIMENT VOLUME- 63.5 x 45 x 56 SPACE FOR THREE EXP.'s THIS SIZE OR ONE THIS SIZE + ONE WITH DIMENSION H-DOUBLE	
MASS[1] - Kg:.	CORE FACILITY - AVAILABLE TO EXPERIMENT- TOTAL	395 306 700
POWER REQUIREMENTS[1] - WATTS:	CORE FACILITY- AVAILABLE TO EXPERIMENT - TOTAL	1400 4110 6000
VOLTAGE[1] - VOLTS:	28dc & 120dc AVAIL. TO EXPERIMENT	
NUMBER OF SAMPLES:	TBD - NO FACILITY LIMIT EXCEPT WEIGHT & POWER - < 1500 PLANNED	
MONITORING CAPABILITY:	TOP LEVEL MONITORING PROVIDED	
SOLUTION CONCENTRATION - MONITORING: CONTROL:	APPARATUS FUNCTION COMMAND INTERFACE COMMAND INTERFACE	
TEMPERATURE REQUIREMENTS - MONITORING: CONTROL:	ENCLOSURE FUNCTION COMMAND INTERFACE COMMAND INTERFACE	
CONTROL CAPABILITY:	TOP LEVEL MONITORING PROVIDED	
CDMS SERVICES:	PROVIDES DATA AND PROGRAM STORAGE	
DOWNLINK KU BAND-[MBPS]:	45	
UPLINK S BAND-[KBPS]:	9	
SSF MULTIPURPOSE APPL. CONSOLE:	FULLTIME	
MULTIPLEXER/DEMULTIPLEXER:	7	
FDDI PER RACK:	ONE/<10 MBPS	
MIL-STD-1553 INTERFACE:	ONE/<700 KBPS	
HDDR LINK/BANDWIDTH:	ONE/<<43 MBPS	
POWER- WATTS:	725	
MASS - Kg:	200	
COST:	$30,260,294	

1.Teledyne Brown Engineering CODR review data, April, 1992
2.Launch condition per-rack limit.

Figure 7.5-16 Core Facility, C-2/APCG-T-2

FACILITY / AUXILLIARY RACK (AO-2/NRA-3)
SUMMARY DESCRIPTION

- ARACK -

DEVELOPER:	TBD
DESCRIPTION:	AUXILLIARY RACK FACILITY
DIMENSIONS [DxWxH] - CM	ALLOWABLE EXPERIMENT VOLUME- 63.5 x 45 x 56; SPACE FOR 7 TOTAL (3 CORE & 4 ARACK) EXP.'s THIS SIZE OR DIMENSION H~DOUBLED[1]
WEIGHT - Kg:	CORE FACILITY- 395 + 350 AVAILABLE TO EXPERIMENT- 306 + 350 TOTAL[2]- 700 + 700
POWER REQUIREMENTS - WATTS:	CORE FACILITY 1400 + 490[3] AVAILABLE TO EXPERIMENT 4110 TOTAL[1] 6000
VOLTAGE - VOLTS:	28dc & 120dc AVAIL. TO EXPERIMENT
NUMBER OF SAMPLES:	NO FACILITY LIMIT EXCEPT WT. OR PWR
MONITORING CAPABILITY:	TOP LEVEL MONITORING PROVIDED
SOLUTION CONCENTRATION - MONITORING: CONTROL:	APRARATUS FUNCTION COMMAND INTERFACE COMMAND INTERFACE
TEMPERATURE REQUIREMENTS - MONITORING: CONTROL:	ENCLOSURE FUNCTION COMMAND INTERFACE COMMAND INTERFACE
CONTROL CAPABILITY	TOP LEVEL CONTROL PROVIDED
CDMS REQUIREMENTS:	ESTIMATED CDMS POWER & MASS INCREASES FOR ADDITIONAL RACK ARE INCLUDED IN ABOVE
COST:	NA

1. Teledyne brown Engineering CODR review, April, 1992
2. Launch condition per rack limit..
3. Values estimated based on 65% requirements sharing with core facility. (ARAK must use 35% of normal CORE allotment).

Figure 7.5-17 Auxilliary Facility Rack, ARACK

8.0 COST SUMMARY

The cost section of the study provides an estimate of the Advanced Protein Crystal Growth Facility (APCGF) program total cost distributed by fiscal year for the baseline and four schedule options. The transition era [Ref. Figures 6.0-1 and 6.0-2] was not cost evaluated for the baseline or other program scenarios. However, the technical description of APCG-T experiment hardware is presented in Section 7.0, and the development costs are given for the three new apparatuses and the TES enclosure on Table 9.0-1. Therefore, as soon as the cost of the transition core facility [43], APCG-T [Figure 6.0-1 and 6.0-2], can be obtained, the computer program developed and explained in Section 10.0 can be used to evaluate this program era as well as any other program scenario where the necessary input data is available or can be assumed. The APCGF program start of development and launch dates used are as follows:

	Start Dev.	Phase 1 Launch	Phase 2 Launch
Baseline	9/1/93	11/1/98	11/1/00
Option 1	9/1/94	11/1/99	11/1/03
Option 2	3/1/95	5/1/00	5/1/03
Option 3	3/1/95	5/1/00	11/1/03
Option 4	9/1/95	11/1/00	11/1/03

Total estimated program cost for the phase 1 and 2 portions of the baseline program is $87.2 million for development and integration of the first flight set of hardware and operation cost is $70.2 million through launch plus 2 years. These amounts are in fiscal year 1992 dollars and the operations cost includes the cost of additional units needed for spares and logistics. A breakdown by major items follows:

Development

Project Management	$ 10.5 M
Systems Engineering & Integration	$ 7.0 M
Design Development Mfg & Test	$ 69.7 M

Operations

Project Management	$ 8.4 M
Systems Engineering & Integration	$ 5.6 M
Production Units & Mission Operations	$ 56.2 M

The APCG baseline microgravity protein crystal growth program provides a man tended SSF flight in November 1998 , and a permanent manned SSF flight in November 2000. The November 1998 man tended flight will provide increased science capability. Four new experiment apparatus systems, one new thermal enclosure system and one new SSF core facility (C-1) will be developed. This

hardware will meet the new science requirements selected from the Advanced Protein Crystal Growth Facility (APCGF) phase one Announcement of Opportunity. The November 2000 permanent manned SSF flight will include development of four additional experiment apparatus systems, one additional thermal enclosure system and one additional SSF core facility (C-2). This APCGF phase two hardware will be developed to meet new science requirements selected from the phase two Announcement of Opportunity. The options provide delays of one to two years in phase one and up to a three year delay in the launch of phase two developed hardware.

Figures 8.0-1 and 8.0-2 show the distribution of the APCGF development and operations cost respectively by year and by major categories of cost for the APCG baseline program schedule.

Tabulated summaries for the baseline and each option are shown in Appendix A, Appendix B includes the bar charts and Appendix C includes the schedules by major program milestones.

The rationale for this programmatic information is supported by program content, schedule, and cost data from prior microgravity programs. The content and schedule was based on program operating plan groundrules and assumptions. The content is further described in the work breakdown structure developed for the study. Cost estimating relationships were developed to determine total cost by major hardware development items: program management, systems engineering and integration, production, and operations. Prior microgravity programs were examined to develop an algorithm for scheduling major milestone dates occurring between authority to proceed with development and launch. An algorithm to distribute total estimated cost by major task was also developed. Assumptions used to define operations cost and schedule are also documented. A computer program was then designed and developed to integrate this information into program cost distributed by major item and by fiscal year using 1992 dollars through launch plus two years. The computer program allows the user to change total cost input for each item of major hardware, the authority to proceed with development dates or launch dates, unit production cost, and numbers of production units thereby providing maximum flexibility for planning options or assessing current projections.

9.0 SUPPORTING COST AND SCHEDULE INFORMATION

The study began with a search for information needed to define baseline program content, schedule, and cost. Information obtained through the Microgravity Projects Office was reviewed, summarized and organized to support development of the program and options.

Program groundrules and assumptions were established for Advanced Protein Crystal Growth, (APCG) Advanced Protein Crystal Growth Transition, (APCG-T), and Advanced Protein Crystal Growth Facility (APCGF) phases of the microgravity program. The APCG and APCG-T projects were reviewed to

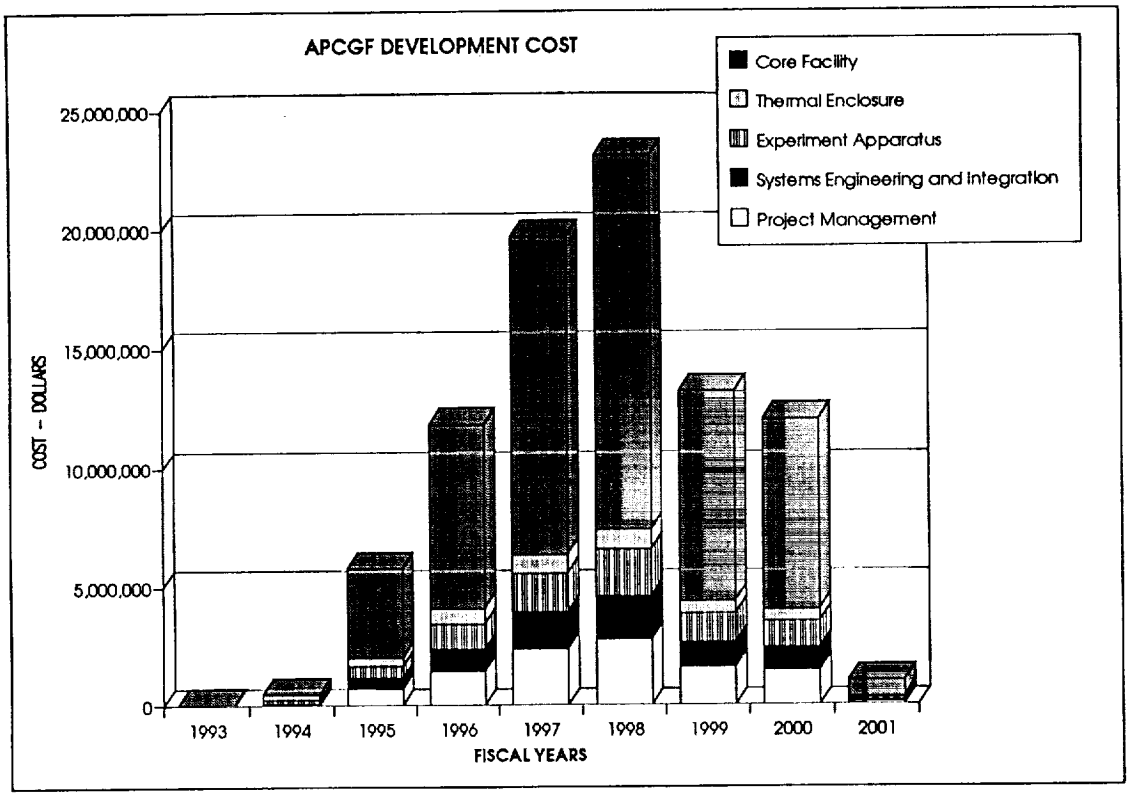
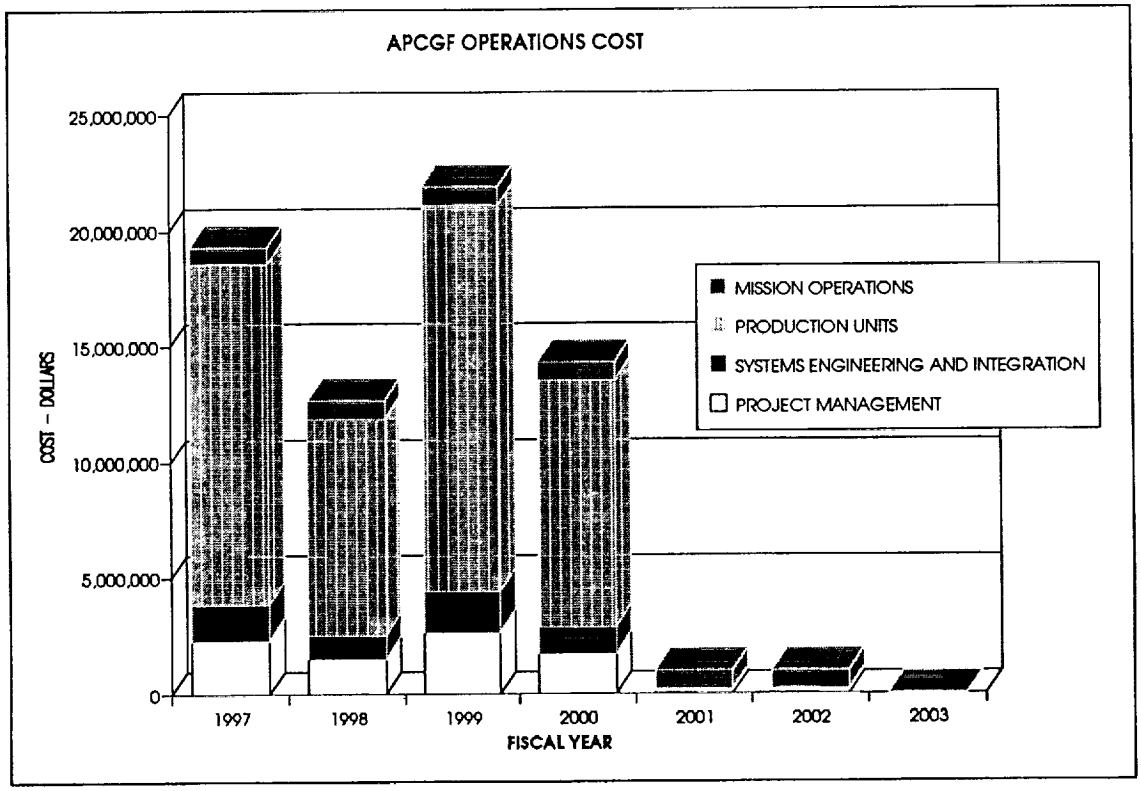


Figure 8.0-1 APCGF Development Cost



F Operations Cost

Figure 8.0-2 APCGF Operations Cost

provide background information on content, schedule, and cost data to be used for the APCGF project and to maintain program continuity. These groundrules and assumptions include key items of experiment hardware, thermal enclosures, and orbital facilities with key schedule development milestones and launch dates as follows:

Advanced Protein Crystal Growth

- Three new experiment apparatus from three Principal Investigators (PI) are to be developed from NASA Research Announcements (NRA) selections in August 1992.
- Two sets of experiment apparatus are to be developed by PI teams and one by NASA.
- Proposers are expected to use the Thermal Exposure System (TES) developed during the Protein Crystal Growth project.
- Four TES flight units are to be available for flight beginning in January 1993.
- Initial APCG flights will utilize the Vapor Diffusion Apparatus.
- Four Mid-Deck Space Shuttle flights per year will be flown from 1993 through 1996.

Advanced Protein Crystal Growth Transition

- Provide for an early Space Station Freedom (SSF) transition flight in late calendar year 1996 or early 1997.
- The SSF transition protein crystal growth flight payload will be Shuttle/Spacelab hardware with operational and design modifications to fly on the SSF.
- Design, manufacturing, and test activities are to begin in late calendar year 1993 or early 1994.
- One core facility will be available for the APCG-T era flight experiments [Ref. APCG-T Figure 6.0-1] payload.
- SSF will be responsible for adaptation of Spacelab hardware to SSF racks and operational environment.
- SSF will be responsible for rack-staging and physical integration of flight racks and for rack level analytical integration.
- APCGT users will be responsible for payload reconfiguration.
- The APCG-T experiments will be delivered to KSC in June 1966 for a May 1997 SSF launch (UF-1).

- **The APCG will be delivered to KSC in August 1996 for a June 1997 optional USML-3 launch.**

Advanced Protein Crystal Growth Facility

- **Four new experiment apparatues are to be developed from each Announcement of Opportunity (AO) or NASA Research Announcement (NRA) selection.**
- **Two PI teams will develop experiment apparatus hardware, and NASA will develop the other two apparatuses for the other two PI teams.**
- **Two APCGF core facilities and two thermal enclosures will be developed by selected PI team leaders.**
- **The conceptual design reviews of the core facility will be in early 1992.**
- **Phase 1 AO/NRA selection will be in 1992 and Phase 2 AO/NRA selection will be in 1995.**
- **Design, manufacturing, and test activities are to begin by fiscal year 1994.**

This information was used to organize the work to be performed and is further defined by the attached Work Breakdown Structure (WBS) and accompanying descriptions of the tasks from which costs are to be estimated. The WBS and descriptions are included in Appendix D.

Cost and schedule information from related microgravity projects was provided by the Microgravity Projects Office and used to develop cost and schedule relationships for the APCGF project. A best fit linear equation relating weight and cost was calculated from the range of data provided and used to estimate the total cost of the Space Station Core Facility Rack. A summary of the microgravity projects and their costs and weights used to derive the equation follows:

Microgravity Facility	Weight Lbs	Cost $ K
1. Geophysical Fluid Flow Cell Reflight	426	8497
2. Crystal Growth Facility	1300	34229
3. Isothermal Dendritic Growth Experiment	660	15877
4. Space Acceleration Measurement System	94	24916

5.	Advanced Automated Solidification Furnace	544	34941
6.	Pool Boiling Experiment	144	7196
7.	Surface Tension Driven Convection Experiment	533	61367
8.	Automated Directional Solidification Furnace	238	21734
9.	Solid Surface Combustion Equipment	118	7734
10.	Critical Fluid Flow Scattering Experiment	922	13147
	Total	4979	229638

A comparison of projected values, using the derived equation, to the actuals from the preceding information are shown Figure 9.0-1.

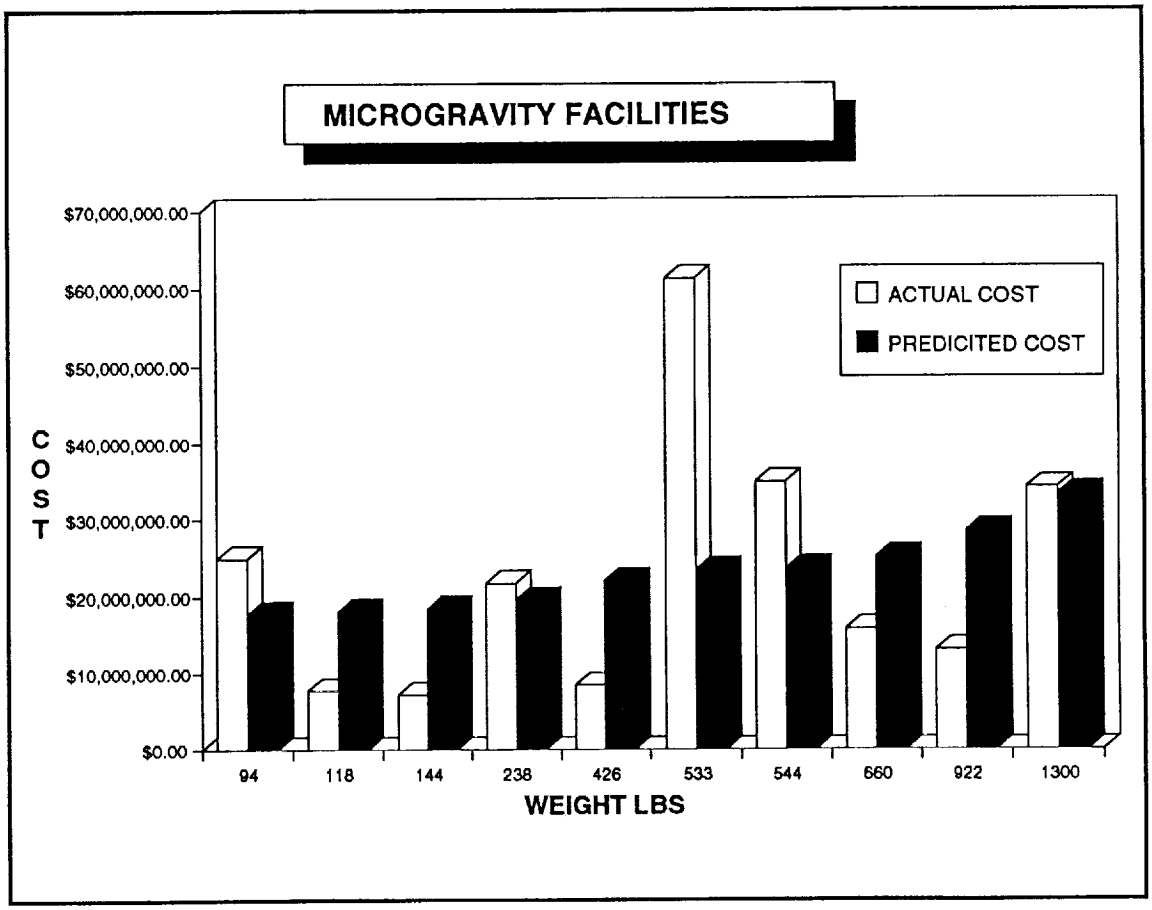


Figure 9.0-1 Microgravity Facilities Cost Versus Weight

The estimated development cost for the Space Station Protein Crystal Growth Facility using the CER equation is $27.8 million. (This is the default value used by the computer program to estimate program cost for phase one of the APCGF project. The program allows different values to be entered for this and all other hardware items.)

Total development cost for experiment apparatus and thermal enclosures were based on expected APCG cost. Additional units for training and backup were estimated at 25 % of the DDT&E and first flight unit cost estimates. Table 9.0-1 summarizes values used for the APCG and APCGF development and production cost estimates.

Table 9.0-1 Hardware Total Cost Estimates

EXPERIMENT APPARATUS	PCG	APCG	APCGF	PROD. UNITS
VDA	1382250			
NRA-1		598000		
NRA-2		649000		
NRA-3		776000		
AO-1			717600	179400
AO-2			778800	194700
AO-3			845219	211305
AO-4			917303	229326
AO-5			995535	248884
AO-6			1080438	270110
AO-7			1172583	293146
AO-8			1272586	318146

THERMAL ENCLOSURE	PCG	APCGF	PROD. UNITS
TES	1260000		290000
CRIM	512000		128000
AO-ENC-1		1575000	393750
AO-ENC-2		2362500	590625

FACILITY	APCGF	PROD. UNITS
C-1	27761738	6940435
C-2	30260294	7565074

The schedule information of related Microgravity Projects was evaluated to determine the average distribution of key project milestones (i.e.) authority to proceed (ATP), preliminary design reviews (PDR),critical design review (CDR),delivery (DEL),launch (LAU). A summary of the projects and milestones used to derive the percentage distribution of days between major milestones is shown in Table 9.0-2.

Table 9.0-2 Microgravity Facilities Key Milestones

MILESTONE	MICROGRAVITY FACILITIES KEY PROGRAM MILESTONES					
	CGF	AADSF	ADSF	PCG	GFFC	MEA/MLR
ATP	1-Jun-87	1-Jan-85	1-Mar-82	1-Jun-86	1-Jul-77	1-Jun-77
SRR	1-Mar-88	1-Jun-85	1-May-82	TBD	1-Aug-77	1-Sep-77
PDR	1-Jun-88	1-Oct-85	1-Sep-82	1-Mar-87	1-May-78	1-Feb-78
CDR	1-Feb-89	1-May-86	1-Feb-83	1-Jun-87	1-Dec-78	1-Oct-78
HWD READY DEL.	1-Apr-90	1-Jun-88	1-Oct-83	1-Dec-87	1-Apr-79	TBD
LAUNCH	1-Aug-90	1-Oct-88	1-Mar-84	1-Feb-88	1-Jul-80	1-Apr-79

The average percent distribution based on the Microgravity Facilities Key Program Milestones is shown in Figure 9.0-2.

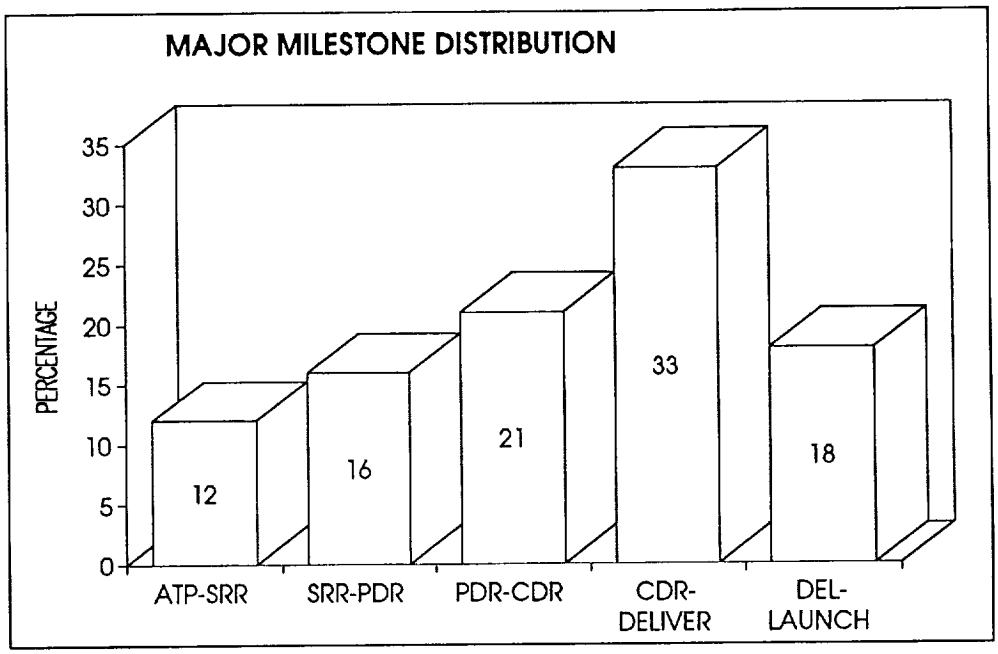


Figure 9.0-2 Major Milestone Distribution

Also included for reference is the average number of years from authority to proceed with development to delivery, and from authority to proceed with development to launch, is shown in Figure 9.0-3.

Having established methods for determining the total cost and for the distribution of key milestone dates the next question to be decided was how much of the total cost should be assigned to the activities between the major milestones. The percent of total cost between major milestones is shown in Figure 9.0-4.

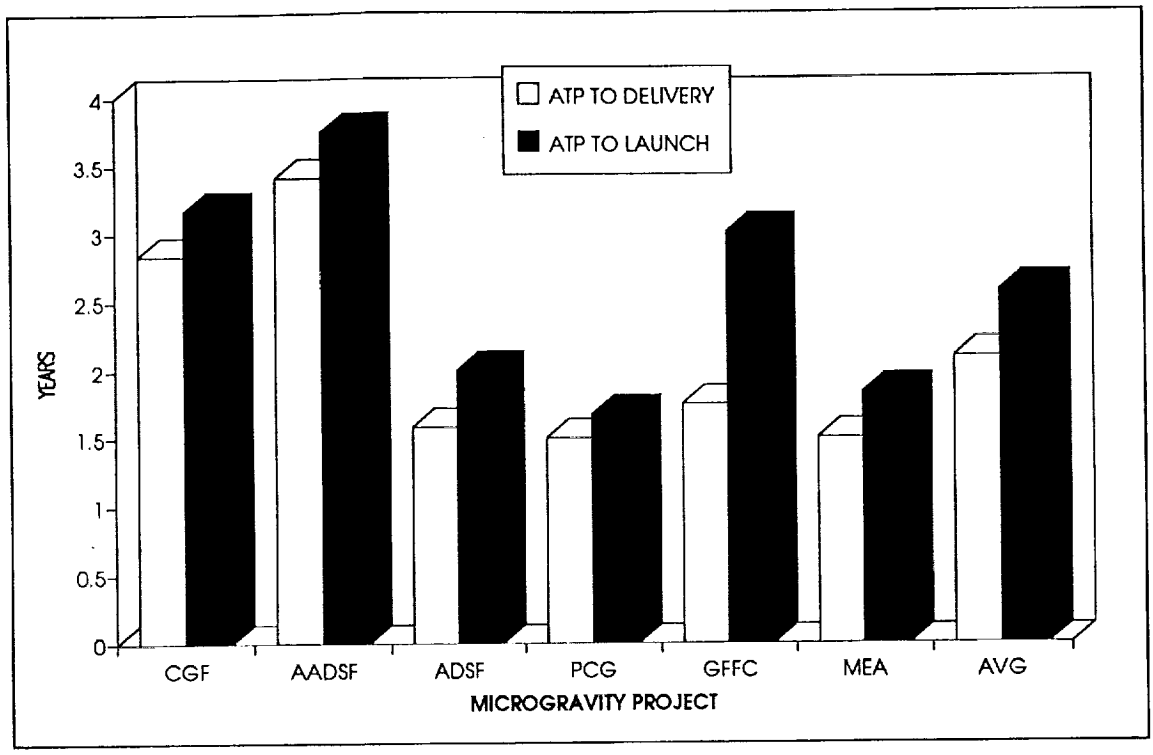


Figure 9.0-3 Development Time In Years

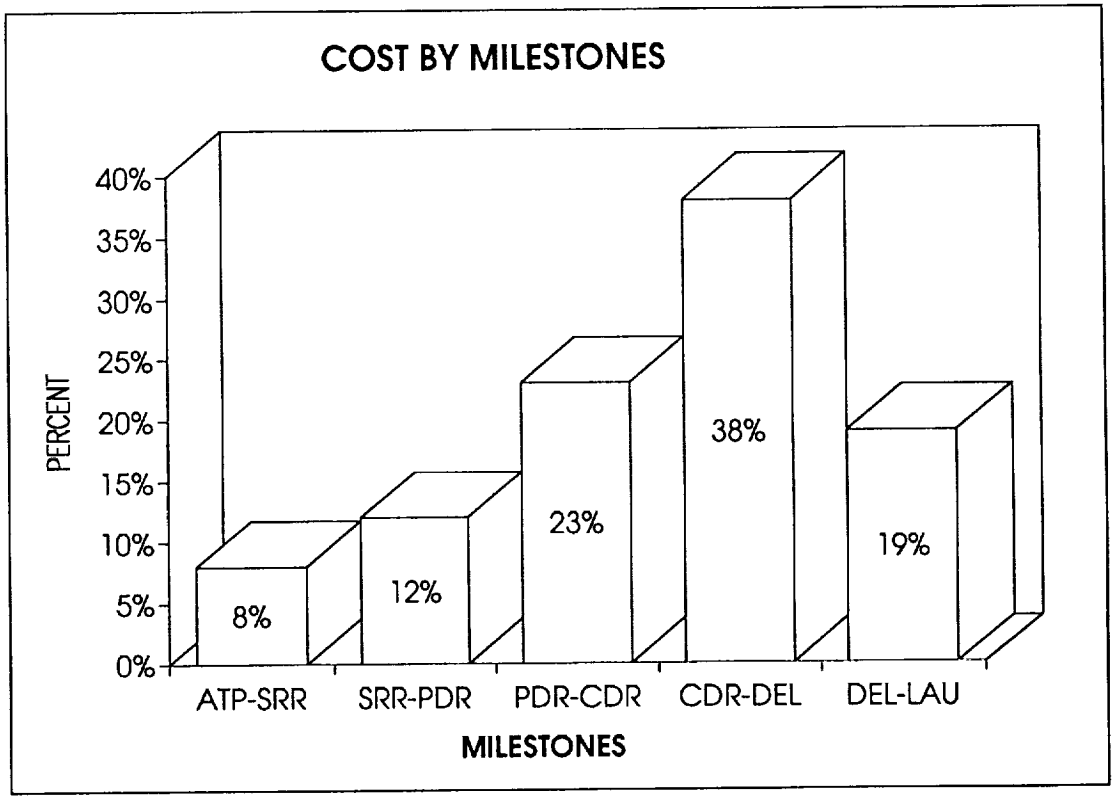


Figure 9.0-4 Cost by Major Milestones

To estimate operations, cost assumptions regarding numbers of additional production units, the schedule for production of these units and for mission operations planning and continuing flight operations were necessary and these assumptions are shown in Figures 9.0-5 and 9.0-6. Level of effort cost of $0.8 million per year was assumed for operations planning and flight.

	OPERATIONS PRODUCTION UNITS					
	DEVELOPMENT UNITS	UNITS REQ PER FLIGHT	ADDITIONAL OPS UNITS	BACKUP UNITS	TRAINING UNITS	TOTAL ADD. PROD. UNITS
EXPERIMENT APPARATUS						
AO-1	1	N/A	0	1	1	2
AO-2	1	N/A	0	1	1	2
AO-3	1	N/A	0	1	1	2
AO-4	1	N/A	0	1	1	2
TOTAL PHASE 1	4	3	0	4	4	8
AO-5	1	N/A	0	1	1	2
AO-6	1	N/A	0	1	1	2
AO-7	1	N/A	0	1	1	2
AO-8	1	N/A	0	1	1	2
TOTAL PHASE 2	4	3	0	4	4	8
THERMAL ENCLOSURES						
AO-ENC-1	1	3	2	1	1	4
AO-ENC-2	1	3	2	1	1	4
TOTAL	2	6	4	2	2	8
FACILITY						
C-1	1	1	0	1	2	3
C-2	1	1	0	1	2	3
TOTAL	2	2	0	2	4	6

Figure 9.0-5 Number of Production Units

PRODUCTION UNITS SCHEDULE

	START L-2 YEARS*	FINISH L-6 MTHS*
EXPERIMENT APPATATUS 1 THRU 4	11/1/96	5/1/98
EXPERIMENT APPARATUS 5 THRU 8	11/1/98	5/1/00
THERMAL ENCLOSURE 1	11/1/96	5/1/98
THERMAL ENCLOSURE 2	11/1/98	5/1/00
RACK 1	11/1/96	5/1/98
RACK 2	11/1/98	5/1/00

NOTE
* TWO YEARS FROM APCGF APPLICABLE LAUNCH DATE
** 6 MONTHS FROM APPLICABLE DATE OF ITEMS

OPERATIONS SCHEDULE

	START L-2 YEARS*	FINISH LAUNCH**
FLIGHT PLANNING	11/1/96	11/1/00

NOTE
* TWO YEARS FROM APCGF PHASE 1 LAUNCH DATE
** APCGF PHASE 2 LAUNCH DATE MINUS 2 YEARS

	START LAUNCH*	FINISH L+2**
MISSION SUPPORT	11/1/98	11/1/02

NOTE
* APCGF PHASE 1 LAUNCH DATE
** APCGF PHASE 2 LAUNCH DATE PLUS 2 YEARS

Figure 9.0-6 Production Units and Operations Schedule

10.0 COMPUTER PROGRAM

A computer program utilizing the information previously described and Excel Windows for IBM computers was developed to build and integrate total program cost. The program builds tabulated and graphical displays for the development (through the first flight unit) and operations (through launch plus 2 years) parts of the APCGF program. The schedule dates for authority to proceed with development of experiment apparatus, thermal enclosures, core facilities, and launch dates for APCGF Phase 1 and Phase 2 based on the previously stated groundrules and assumptions have been used as default values. Total cost estimates for the development items, additional operations production units quantities and cost, flight operations planning cost, and flight operations support cost have also been included as default values. *The program allows the user to choose and input different values.* After choosing these values, the program distributes cost and tasks (using the algorithms developed from the supporting information) by the correct fiscal years. and provides tabulated summaries of major cost items by fiscal year. Bar and line graph summaries are also provided. A flow chart for the computer program is shown in Figures 10.0-1, 10.0-2, and 10.0-3.

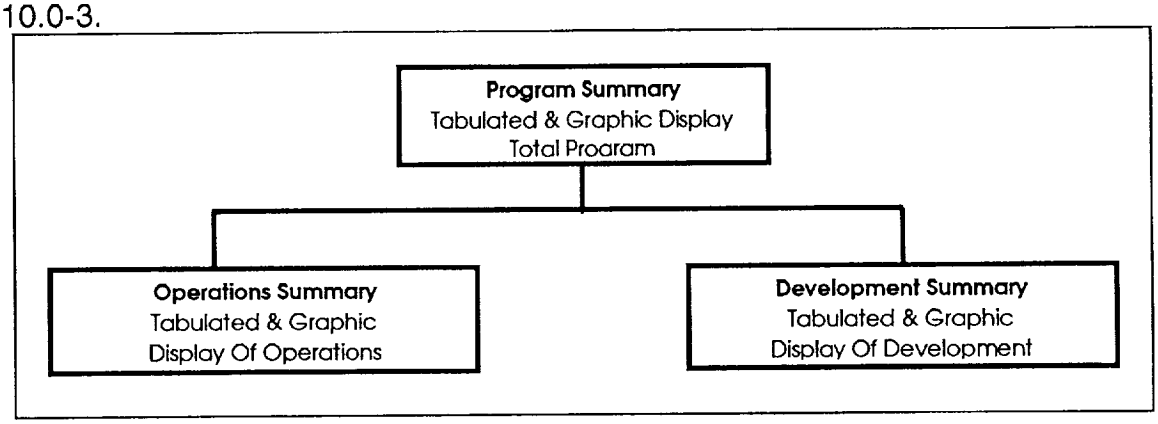


Figure 10.0-1 Program Summary Flow Chart

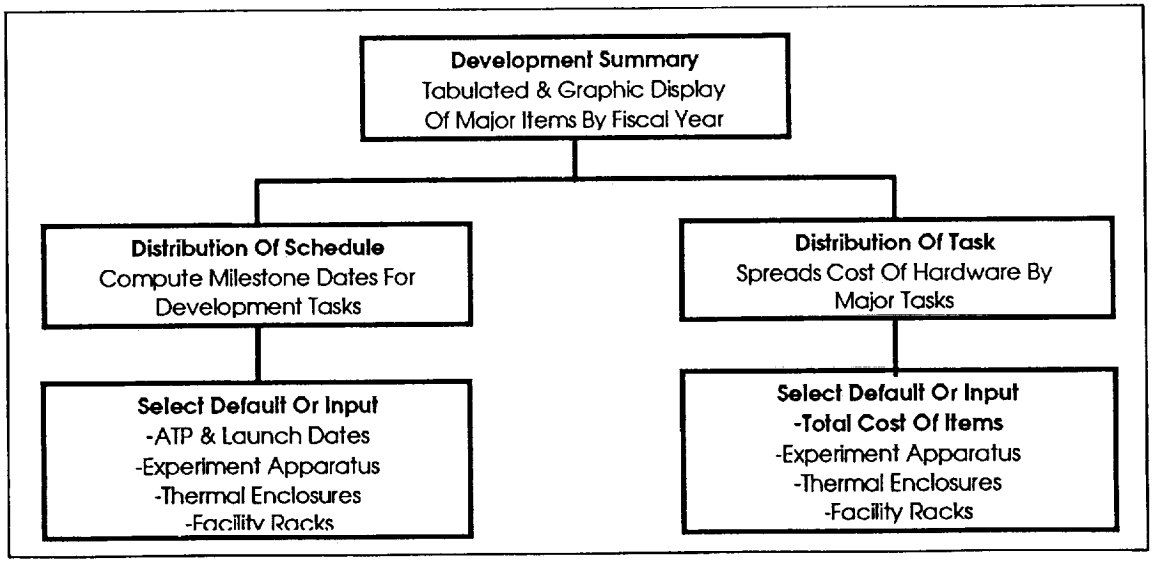


Figure 10.0-2 Development Flow Chart

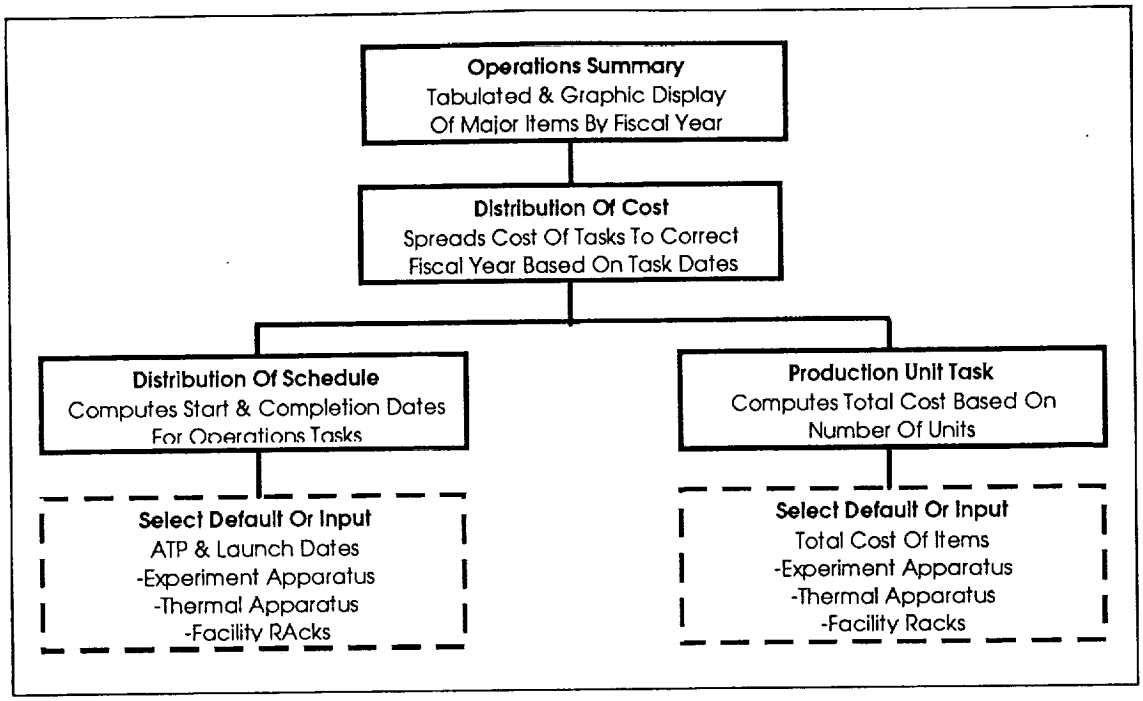


Figure 10.0-3 Operations Flow Chart

The computer program operating procedure and a list of computer files are included in Appendix E.

11.0 CONCLUSIONS & RECOMMENDATIONS

The data generated through this study are very timely, and applicable over a wide range of protein crystal growth activities. The approach and assessment methods used in producing these evaluations were a combination of innovation, experience, and application of proven evaluation and analysis methods. The unique qualities of this study permit the continuous incorporation of future, additional, actual design and experiment data and experience as it becomes available. And, the incorporation of additional existing data will validate these methods or indicate where modifications would be beneficial. This feature encourages increasing and/or updating the reference data base thereby increasing the confidence level for future management planning decisions made using the methods developed in this study.

Several technical and cost/programmatic conclusions and recommendations are made based on what was learned during conduct of this study. These are summarized below.

The literature search and personal contact with principle investigators and NASA scientists indicate that emphasis should be placed on: a. increasing the reliability of growing quality protein crystals in a microgravity environment in large quantities; and, b. on improved analysis techniques both on-orbit and during ground research. Improved methods of real-time monitoring and control are required to better understand the crystal growth processes so that

optimization may significantly increase the quantity and quality of space grown crystals.

More in-depth analysis and evaluation of the other identified (~20) basic parameters, and their resulting impacts when combined to form a total experiment configuration, would further benefit the correlation of experiment cost and complexity.

Historical causes of microgravity project schedule delays after phase C/D approval for development should be investigated. Major factors and typical impact on schedule, modifications in the appropriate distribution algorithms, and integration of results into the model should be done.

Protein Crystal Growth (PCG), and Advanced Protein Crystal Growth (APCGF), cost histories should be investigated in more detail to validate the summary information provided and if necessary adjust the total cost estimates for experiment apparatus, and thermal enclosures.

The Microgravity Projects historical cost, including the weight versus cost data that was provided to assess the major causes of variance between projects should be investigated in more detail, and adjusted where necessary.

An operations logistics study to further define and validate cost assumptions for numbers of additional production units, pre and post-flight integration activity for reflights, and mission operations activity for flight planning, flight operation and post-flight analysis should be performed.

Additional effort should be expended in search of existing data that has not been cataloged, or has been cataloged since our search was concluded. Several documents were found during a second cursory search that were not previously identifiable. The mid-1992 NRA experiment design selections should be evaluated and incorporated

The parameter, number of samples, by itself does not impact the power and/or mass requirements significantly; however, when coupled with real-time monitoring and control of video, temperature ramp and solution concentration for large numbers of samples, the experiment power requirements are relatively large.

The power and mass allocations used in this study are more than adequate for the experiments defined, and allow for considerable requirement/capability expansion.

The addition of the ARACK (auxiliary facility rack) in option 3 provides the potential for significant additional requirements in both mass and power, allowing more than twice the number of experiments.

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APPENDIX A

TABULATED COST SUMMARY

ADVANCED PROTEIN CRYSTAL GROWTH FACILITY
DEVELOPMENT COST THROUGH FIRST FLIGHT
BASELINE SCHEDULE
FY 92 DOLLARS

TITLE	1993	1994	1995	1996	1997	1998	1999	2000	2001	TOTAL
Development	30,898	458,330	5,791,397	11,847,529	19,693,820	23,096,565	13,204,377	12,042,820	1,008,758	87,174,495
Project Management	3,708	55,000	694,968	1,421,704	2,363,258	2,771,588	1,584,525	1,445,138	121,051	10,460,939
Systems Engineering and Integration	2,472	36,666	463,312	947,802	1,575,506	1,847,725	1,056,350	963,426	80,701	6,973,960
Design, Development, Manufacturing & Test	24,718	366,664	4,633,118	9,478,024	15,755,056	18,477,252	10,563,502	9,634,256	807,007	69,739,596
Experiment Apparatus	7,737	153,760	495,039	1,073,786	1,643,514	1,948,782	1,224,522	1,135,410	97,513	7,780,064
Experiment Apparatus 1	7,737	97,003	132,259	153,320	158,670	155,559	13,052			717,600
Experiment Apparatus 2		56,757	136,489	185,157	194,045	190,687	15,665			778,800
Experiment Apparatus 3			135,362	211,963	241,303	237,258	19,333			845,219
Experiment Apparatus 4			59,768	230,012	301,385	300,428	25,710			917,303
Experiment Apparatus 5			31,160	133,332	184,441	208,322	211,637	208,684	17,959	995,535
Experiment Apparatus 6				114,821	193,122	245,102	255,069	250,655	21,670	1,080,438
Experiment Apparatus 7				45,182	197,557	292,453	307,849	303,959	25,582	1,172,583
Experiment Apparatus 8					172,991	318,973	376,205	372,112	32,303	1,272,586
Thermal Enclosure	16,981	212,904	364,232	652,917	785,947	835,791	530,883	495,226	42,618	3,937,500
Thermal Enclosure 1	16,981	212,904	290,285	336,509	348,251	341,423	28,647			1,575,000
Thermal Enclosure 2			73,947	316,408	437,697	494,368	502,236	495,226	42,618	2,362,500
Core Facility	0	0	3,773,847	7,751,320	13,325,595	15,692,678	8,808,096	8,003,620	666,876	58,022,032
Rack 1			3,773,847	6,958,469	8,229,641	8,095,080	704,701			27,761,738
Rack 2				792,851	5,095,954	7,597,598	8,103,395	8,003,620	666,876	30,260,294

ADVANCED PROTEIN CRYSTAL GROWTH FACILITY
OPERATIONS COST THROUGH LAUNCH PLUS 2 YEARS
BASELINE SCHEDULE
FY 92 DOLLARS

TITLE	1997	1998	1999	2000	2001	2002	2003	TOTAL
OPERATIONS	19,305,796	12,656,467	21,885,632	14,290,198	1,013,982	1,013,982	17,354	70,183,411
PROJECT MANAGEMENT	2,316,696	1,518,776	2,626,276	1,714,824	121,678	121,678	2,082	8,422,009
SYSTEMS ENGINEERING AND INTEGRATION	1,544,464	1,012,517	1,750,851	1,143,216	81,119	81,119	1,388	5,614,673
PRODUCTION UNITS	14,711,777	9,313,988	16,697,319	10,620,972	0	0	0	51,344,057
APPARATUS 1 THRU 4	997,774	631,688	0					1,629,461
APPARATUS 5 THRU 8			1,381,692	878,879	0			2,260,571
ENCLOSURE 1	964,425	610,575	0					1,575,000
ENCLOSURE 2			1,443,993	918,507	0			2,362,500
RACK 1	12,749,578	8,071,725	0					20,821,304
RACK 2			13,871,634	8,823,587	0			22,695,221
MISSION OPERATIONS	732,860	811,186	811,186	811,186	811,186	811,186	13,883	4,802,672

ADVANCED PROTEIN CRYSTAL GROWTH FACILITY
DEVELOPMENT COST THROUGH FIRST FLIGHT
OPTION 1 SCHEDULE
FY 92 DOLLARS

TITLE	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	TOTAL
Development	30,898	458,330	5,775,118	11,311,174	16,934,287	18,149,754	8,996,129	8,367,106	8,370,611	8,103,925	677,162	0	87,174,495
Project Management	3,708	55,000	693,014	1,357,341	2,032,114	2,177,970	1,079,535	1,004,053	1,004,473	972,471	81,259	0	10,460,939
Systems Engineering and Integration	2,472	36,666	462,009	904,894	1,354,743	1,451,980	719,690	669,368	669,649	648,314	54,173	0	6,973,960
Design, Development, Manufacturing & Test	24,718	366,664	4,620,095	9,048,939	13,547,430	14,519,803	7,196,903	6,693,685	6,696,489	6,483,140	541,730	0	69,739,596
Experiment Apparatus	7,737	153,760	487,534	983,980	1,359,469	1,523,243	835,869	792,969	794,559	775,669	65,275	0	7,780,064
Experiment Apparatus 1	7,737	97,003	132,259	153,320	158,670	155,559	13,052						717,600
Experiment Apparatus 2		56,757	136,989	184,657	194,045	190,687	15,665						778,800
Experiment Apparatus 3			135,788	212,158	240,681	237,258	19,333						845,219
Experiment Apparatus 4			59,816	229,259	301,409	301,229	25,591						917,303
Experiment Apparatus 5			22,681	94,364	108,027	146,149	151,732	154,058	154,569	150,874	13,081		995,535
Experiment Apparatus 6				79,292	115,897	159,933	174,054	180,224	180,516	175,278.98	15,243		1,080,438
Experiment Apparatus 7				30,929	130,427	164,676	201,123	211,174	211,174	205,883.14	17,197		1,172,583
Experiment Apparatus 8					110,314	167,753	235,319	247,513	248,300	243,632.47	19,755		1,272,586
Thermal Enclosure	16,981	212,904	344,109	560,445	604,609	688,248	388,721	365,594	366,808	358,040	31,041	0	3,937,500
Thermal Enclosure 1	16,981	212,904	290,285	336,509	348,251	341,423	28,647						1,575,000
Thermal Enclosure 2			53,825	223,936	256,358	346,825	360,073	365,594	366,808	358,040	31,041		2,362,500
Core Facility	0	0	3,788,452	7,504,515	11,583,352	12,308,312	5,972,314	5,535,122	5,535,122	5,349,432	445,413	0	58,022,032
Rack 1			3,788,452	6,965,182	8,208,324	8,095,080	704,701						27,761,738
Rack 2				539,333	3,375,028	4,213,233	5,267,612	5,535,122	5,535,122	5349431.8	445,413		30,260,294

ADVANCED PROTEIN CRYSTAL GROWTH FACILITY
OPERATIONS COST THROUGH LAUNCH PLUS 2 YEARS
OPTION 1 SCHEDULE
FY 92 DOLLARS

TITLE	1998	1999	2000	2001	2002	2003	2004	2005	2006	TOTAL
OPERATIONS	19,305,796	12,653,247	1,010,762	1,010,762	21,924,050	14,245,338	1,010,762	1,010,762	12,134	72,183,611
PROJECT MANAGEMENT	2,316,696	1,518,390	121,291	121,291	2,630,886	1,709,441	121,291	121,291	1,456	8,662,033
SYSTEMS ENGINEERING AND INTEGRATION	1,544,464	1,012,260	80,861	80,861	1,753,924	1,139,627	80,861	80,861	971	5,774,689
PRODUCTION UNITS	14,711,777	9,313,988	0	0	16,730,631	10,587,661	0	0	0	51,344,057
APPARATUS 1 THRU 4	997,774	631,688	0							1,629,461
APPARATUS 5 THRU 8					1,384,449	876,122	0			2,260,571
ENCLOSURE 1	964,425	610,575	0							1,575,000
ENCLOSURE 2					1,446,874	915626.39	0			2,362,500
RACK 1	12,749,578	8,071,725	0							20,821,304
RACK 2					13,899,308	8795912.5	0			22,695,221
MISSION OPERATIONS	732,860	808,609	808,609	808,609	808,609	808,609	808,609	808,609	9,707	6,402,832

ADVANCED PROTEIN CRYSTAL GROWTH FACILITY
DEVELOPMENT COST THROUGH FIRST FLIGHT
OPTION 2 SCHEDULE
FY 92 DOLLARS

TITLE	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	TOTAL
Development	216,107	2,169,564	8,647,707	15,558,280	19,039,280	16,166,438	9,879,336	9,869,621	5,628,161	0	87,174,495
Project Management	25,933	260,348	1,037,725	1,866,994	2,284,714	1,939,973	1,185,520	1,184,355	675,379	0	10,460,939
Systems Engineering and Integration	17,289	173,565	691,817	1,244,662	1,523,142	1,293,315	790,347	789,570	450,253	0	6,973,960
Design, Development, Manufacturing & Test	172,886	1,735,651	6,918,166	12,446,624	15,231,424	12,933,150	7,903,469	7,895,697	4,502,529	0	69,739,596
Experiment Apparatus	54,546	286,790	759,303	1,263,345	1,609,045	1,401,070	936,798	934,256	534,911	0	7,780,064
Experiment Apparatus 1	54,130	108,866	149,621	157,284	157,546	90,152	0				717,600
Experiment Apparatus 2	416	119,074	166,224	190,343	192,500	110,244	0				778,800
Experiment Apparatus 3		58,850	175,700	233,229	240,426	137,013	0				845,219
Experiment Apparatus 4			157,831	279,118	307,156	173,199	0				917,303
Experiment Apparatus 5			79,292	116,052	167,092	175,529	178,184	177,467	101,919	0	995,535
Experiment Apparatus 6			30,634	131,049	175,332	202,685	210,718	209,728	120,292	0	1,080,438
Experiment Apparatus 7				112,721	180,032	238,711	249,532	249,309	142,277	0	1,172,583
Experiment Apparatus 8				43,548	188,960	273,538	298,365	297,752	170,422	0	1,272,586
Thermal Enclosure	118,340	238,542	516,518	620,629	742,265	615,404	422,745	421,236	241,820	0	3,937,500
Thermal Enclosure 1	118,340	238,542	328,309	345,961	346,060	197,787	0				1,575,000
Thermal Enclosure 2			188,209	274,668	396,205	417,617	422,745	421,236	241,820	0	2,362,500
Core Facility	0	1,210,319	5,642,345	10,562,650	12,880,114	10,916,676	6,543,926	6,540,205	3,725,799	0	58,022,032
Rack 1		1,210,319	5,642,345	7,951,946	8,284,877	4,672,251	0				27,761,738
Rack 2				2,610,704	4,595,236	6,244,425	6,543,926	6,540,205	3,725,799	0	30,260,294

ADVANCED PROTEIN CRYSTAL GROWTH FACILITY
OPERATIONS COST THROUGH LAUNCH PLUS 2 YEARS
OPTION 2 SCHEDULE
FY 92 DOLLARS

TITLE	1998	1999	2000	2001	2002	2003	2004	2005	2006	TOTAL
OPERATIONS	8,700,006	21,176,669	2,731,889	10,633,057	23,867,945	2,892,167	1,081,768	97,270	0	71,180,771
PROJECT MANAGEMENT	1,044,001	2,541,200	327,827	1,275,967	2,864,153	347,060	129,812	11,672	0	8,541,692
SYSTEMS ENGINEERING AND INTEGRATION	696,000	1,694,134	218,551	850,645	1,909,436	231,373	86,541	7,782	0	5,694,462
PRODUCTION UNITS	6,629,747	16,075,921	1,320,097	7,641,031	18,228,942	1,448,319	0	0	0	51,344,057
APPARATUS 1 THRU 4	449,639	1,090,292	89,531							1,629,461
APPARATUS 5 THRU 8				632,290	1,508,433	119,847				2,260,571
ENCLOSURE 1	434,611	1,053,851	86,538							1,575,000
ENCLOSURE 2				660,800	1,576,448	125,251				2,362,500
RACK 1	5,745,498	13,931,778	1,144,028							20,821,304
RACK 2				6,347,940	15,144,060	1,203,220				22,695,221
MISSION OPERATIONS	330,258	865,414	865,414	865,414	865,414	865,414	865,414	77,816	0	5,600,560

ADVANCED PROTEIN CRYSTAL GROWTH FACILITY
DEVELOPMENT COST THROUGH FIRST FLIGHT
OPTION 3 SCHEDULE
FY 92 DOLLARS

TITLE	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	TOTAL
Development	216,107	2,169,564	8,620,018	15,171,181	18,083,737	15,238,800	9,001,666	9,070,378	8,876,604	726,440	87,174,495
Project Management	25,933	260,348	1,034,402	1,820,542	2,170,048	1,828,656	1,080,200	1,088,445	1,065,193	87,173	10,460,939
Systems Engineering and Integration	17,289	173,565	689,601	1,213,695	1,446,699	1,219,104	720,133	725,630	710,128	58,115	6,973,960
Design, Development, Manufacturing & Test	172,886	1,735,651	6,896,014	12,136,945	14,466,989	12,191,040	7,201,333	7,256,303	7,101,283	581,152	69,739,596
Experiment Apparatus	54,546	286,790	751,023	1,228,928	1,522,724	1,307,847	855,209	859,452	842,623	70,924	7,780,064
Experiment Apparatus 1	54,130	108,866	149,621	157,284	157,546	90,152	0				717,600
Experiment Apparatus 2	416	119,074	166,224	190,343	192,500	110,244	0				778,800
Experiment Apparatus 3		58,850	175,700	233,229	240,426	137,013	0				845,219
Experiment Apparatus 4			157,831	279,118	307,156	173,199	0				917,303
Experiment Apparatus 5			73,450	106,909	147,613	160,029	165,777	166,197	161,527	14,034	995,535
Experiment Apparatus 6			28,197	120,161	152,089	185,291	194,575	194,575	189,786	15,764	1,080,438
Experiment Apparatus 7				102,448	154,930	216,286	227,885	228,364	224,277	18,394	1,172,583
Experiment Apparatus 8				39,435	170,464	235,634	266,972	270,316	267,033	22,732	1,272,586
Thermal Enclosure	118,340	238,542	502,646	598,982	696,052	577,455	394,384	394,481	383,307	33,311	3,937,500
Thermal Enclosure 1	118,340	238,542	328,309	345,961	346,060	197,787	0				1,575,000
Thermal Enclosure 2			174,338	253,021	349,992	379,668	394,384	394,481	383,307	33,311	2,362,500
Core Facility	0	1,210,319	5,642,345	10,309,035	12,248,213	10,305,738	5,951,740	6,002,371	5,875,354	476,918	58,022,032
Rack 1		1,210,319	5,642,345	7,951,946	8,284,877	4,672,251	0				27,761,738
Rack 2				2,357,090	3,963,336	5,633,487	5,951,740	6,002,371	5,875,354	476,918	30,260,294

ADVANCED PROTEIN CRYSTAL GROWTH FACILITY
OPERATIONS COST THROUGH LAUNCH PLUS 2 YEARS
OPTION 3 SCHEDULE
FY 92 DOLLARS

TITLE	1998	1999	2000	2001	2002	2003	2004	2005	2006	TOTAL
OPERATIONS	8,700,006	21,106,316	2,661,536	1,011,415	21,924,703	14,245,991	1,011,415	1,011,415	12,134	71,684,931
PROJECT MANAGEMENT	1,044,001	2,532,758	319,384	121,370	2,630,964	1,709,519	121,370	121,370	1,456	8,602,192
SYSTEMS ENGINEERING AND INTEGRATION	696,000	1,688,505	212,923	80,913	1,753,976	1,139,679	80,913	80,913	971	5,734,794
PRODUCTION UNITS	6,629,747	16,075,921	1,320,097	0	16,730,631	10,587,661	0	0	0	51,344,057
APPARATUS 1 THRU 4	449,639	1,090,292	89,531							1,629,461
APPARATUS 5 THRU 8					1,384,449	876,122	0			2,260,571
ENCLOSURE 1	434,611	1,053,851	86,538							1,575,000
ENCLOSURE 2					1,446,874	915626.39	0			2,362,500
RACK 1	5,745,498	13,931,778	1,144,028							20,821,304
RACK 2					13,899,308	8795912.5	0			22,695,221
MISSION OPERATIONS	330,258	809,132	809,132	809,132	809,132	809,132	809,132	809,132	9,707	6,003,888

ADVANCED PROTEIN CRYSTAL GROWTH FACILITY
DEVELOPMENT COST THROUGH FIRST FLIGHT
OPTION 4 SCHEDULE
FY 92 DOLLARS

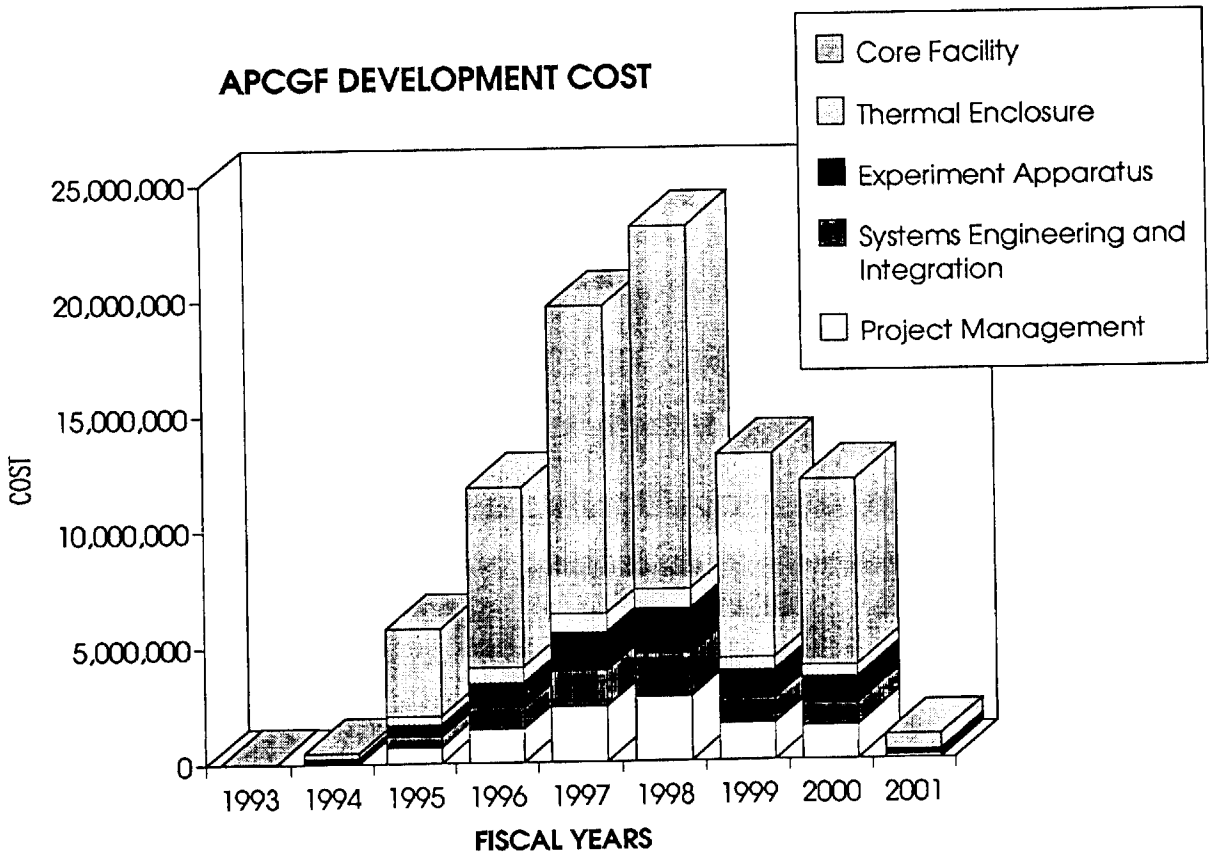
TITLE	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	TOTAL
Development	30,881	459,365	5,805,786	11,524,290	18,001,716	20,174,186	10,699,407	9,920,341	9,736,343	822,179	87,174,495
Project Management	3,706	55,124	696,694	1,382,915	2,160,206	2,420,902	1,283,929	1,190,441	1,168,361	98,661	10,460,939
Systems Engineering and Integration	2,471	36,749	464,463	921,943	1,440,137	1,613,935	855,953	793,627	778,907	65,774	6,973,960
Design, Development, Manufacturing & Test	24,705	367,492	4,644,629	9,219,432	14,401,373	16,139,349	8,559,526	7,936,273	7,789,075	657,743	69,739,596
Experiment Apparatus	7,733	154,019	517,954	1,020,586	1,455,026	1,685,172	1,000,009	940,287	922,925	76,352	7,780,064
Experiment Apparatus 1	7,733	97,262	132,364	152,917	158,296	155,488	13,540				717,600
Experiment Apparatus 2		56,757	136,489	184,626	194,045	190,701	16,182				778,800
Experiment Apparatus 3			135,362	211,963	240,643	237,275	19,976				845,219
Experiment Apparatus 4			87,480	229,968	288,002	286,489	25,364				917,303
Experiment Apparatus 5			26,259	110,734	139,812	170,755	179,289	179,289	174,797	14,600	995,535
Experiment Apparatus 6				93,657	142,424	199,788	210,141	210,809	206,846	16,772	1,080,438
Experiment Apparatus 7				36,721	157,076	216,635	246,005	249,861	245,905	20,380	1,172,583
Experiment Apparatus 8					134,729	228,040	289,512	300,327	295,377	24,600	1,272,586
Thermal Enclosure	16,972	213,472	352,828	598,407	679,218	746,486	455,188	425,471	414,810	34,648	3,937,500
Thermal Enclosure 1	16,972	213,472	290,514	335,626	347,431	341,267	29,718				1,575,000
Thermal Enclosure 2			62,315	262,781	331,787	405,219	425,471	425,471	414,810	34,648	2,362,500
Core Facility	0	0	3,773,847	7,600,439	12,267,129	13,707,691	7,104,328	6,570,515	6,451,340	546,743	58,022,032
Rack 1			3,773,847	6,958,469	8,207,006	8,117,715	704,701				27,761,738
Rack 2				641,970	4,060,123	5,589,976	6,399,627	6,570,515	6,451,340	546,743	30,260,294

ADVANCED PROTEIN CRYSTAL GROWTH FACILITY
OPERATIONS COST THROUGH LAUNCH PLUS 2 YEARS
OPTION 4 SCHEDULE
FY 92 DOLLARS

TITLE	1999	2000	2001	2002	2003	2004	2005	2006	2007	TOTAL
OPERATIONS	19,248,052	12,709,691	1,012,201	21,925,490	14,246,777	1,012,201	1,012,201	14,157	0	71,180,771
PROJECT MANAGEMENT	2,309,766	1,525,163	121,464	2,631,059	1,709,613	121,464	121,464	1,699	0	8,541,692
SYSTEMS ENGINEERING AND INTEGRATION	1,539,844	1,016,775	80,976	1,754,039	1,139,742	80,976	80,976	1,133	0	5,694,462
PRODUCTION UNITS	14,667,773	9,357,991	0	16,730,631	10,587,661	0	0	0	0	51,344,057
APPARATUS 1 THRU 4	994,789	634,672	0	1,384,449	876,122	0	0			1,629,461
APPARATUS 5 THRU 8										2,260,571
ENCLOSURE 1	961,540	613,460	0	1,446,874	915,626	0	0			1,575,000
ENCLOSURE 2										2,362,500
RACK 1	12,711,444	8,109,860	0	13,899,308	8,795,912	0	0			20,821,304
RACK 2										22,695,221
MISSION OPERATIONS	730,668	809,761	809,761	809,761	809,761	809,761	809,761	11,325		5,600,560

APPENDIX B

BAR CHART COST SUMMARIES


APCGF DEVELOPMENT COST
Core Facility
Thermal Enclosure
Experiment Apparatus
Systems Engineering and Integration
Project Management
25,000,000
20,000,000
15,000,000
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COST
1993
1994
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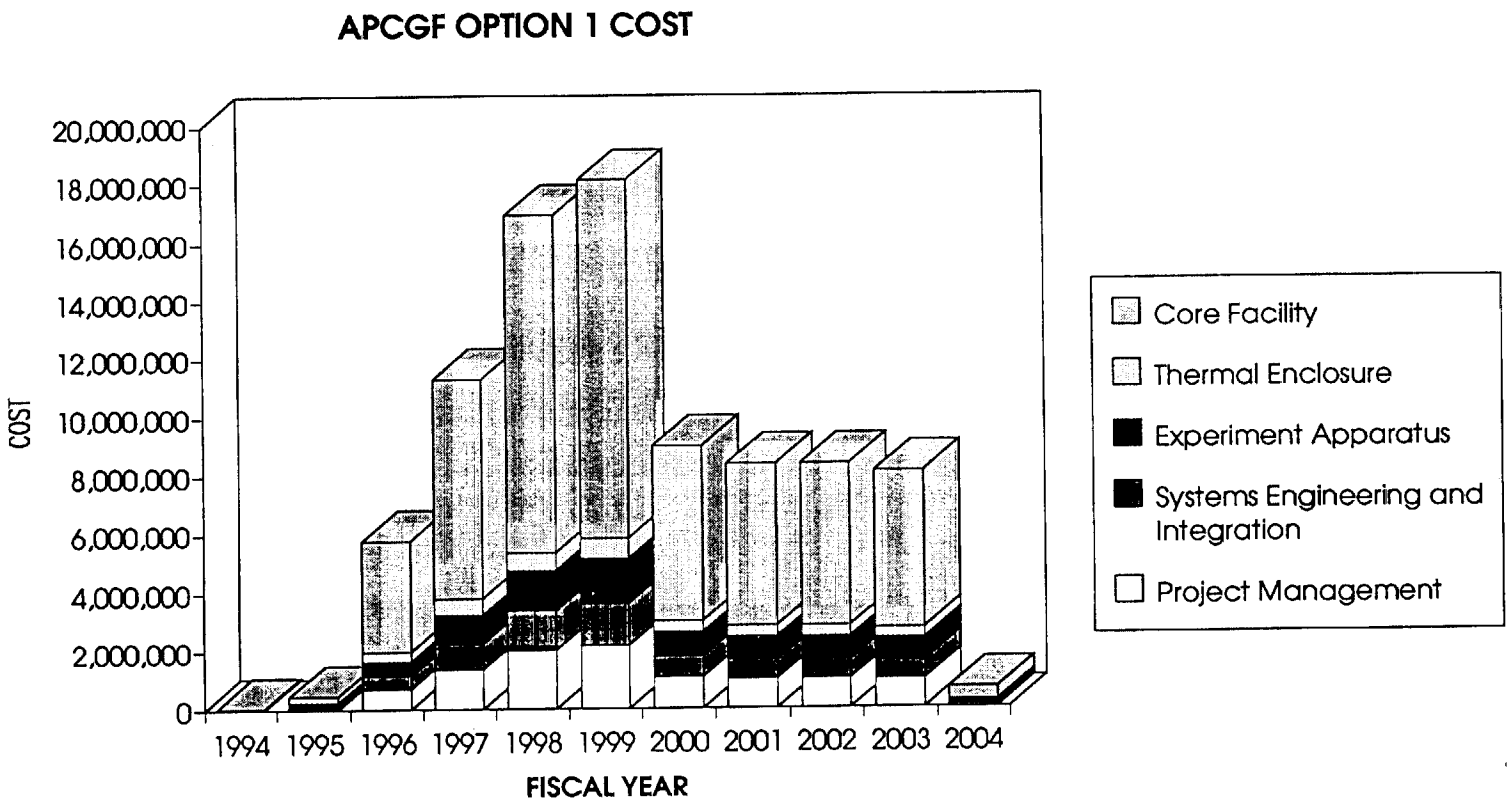
FISCAL YEARS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COST
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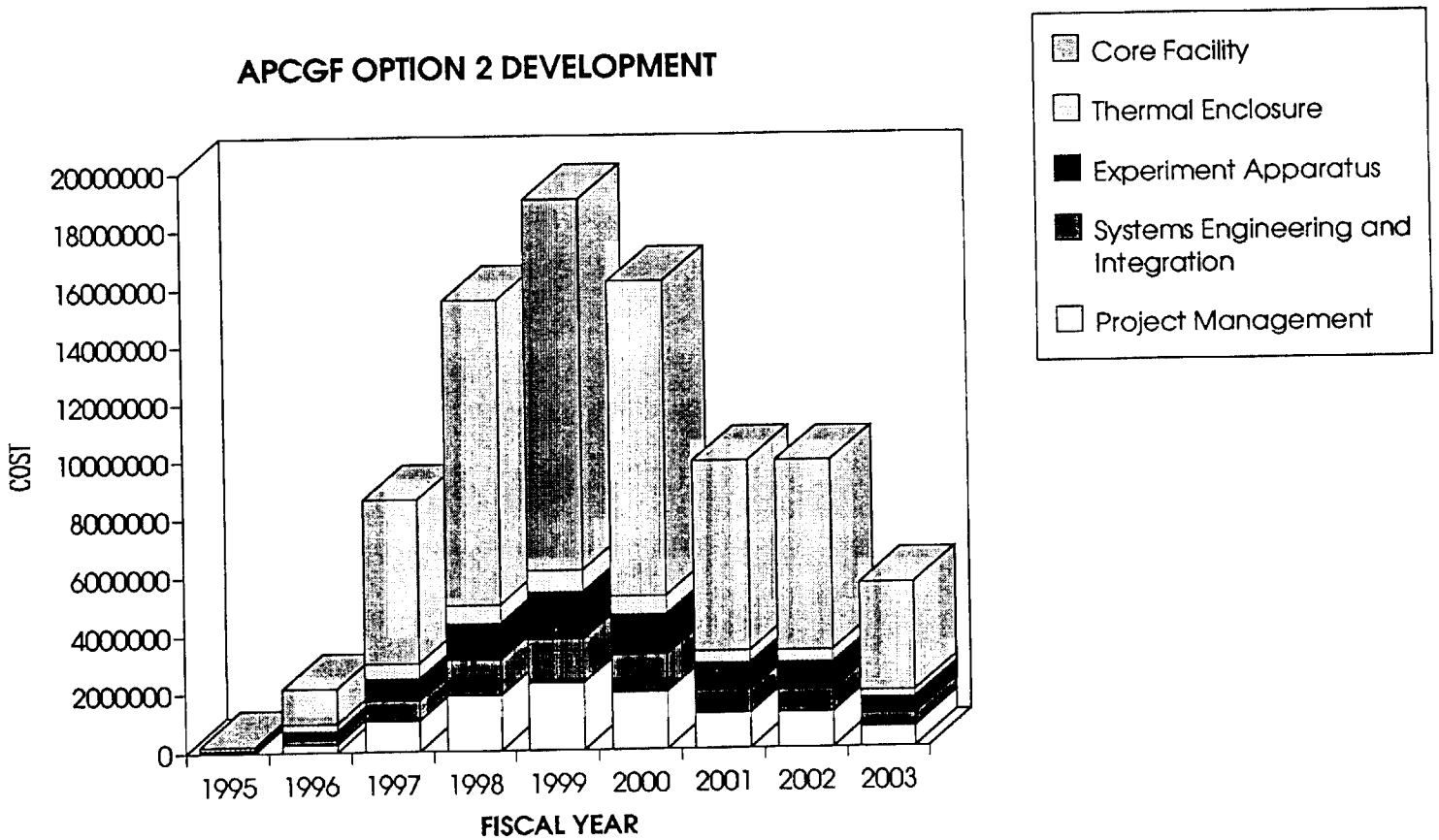
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
FISCAL YEAR
Core Facility
Thermal Enclosure
Experiment Apparatus
Systems Engineering and Integration
Project Management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COST
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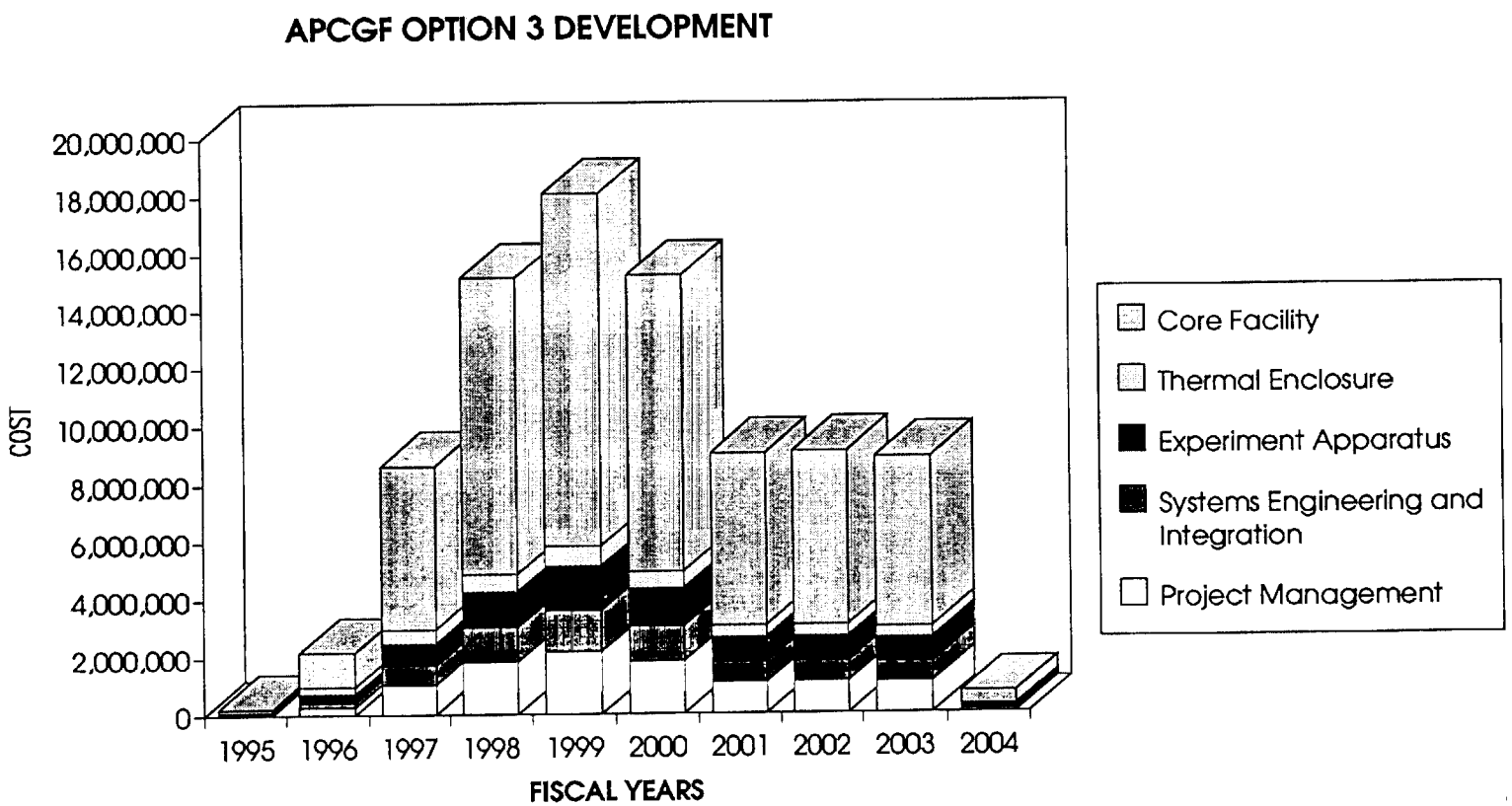
FISCAL YEAR
Core Facility
Thermal Enclosure
Experiment Apparatus
Systems Engineering and Integration
Project Management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COST
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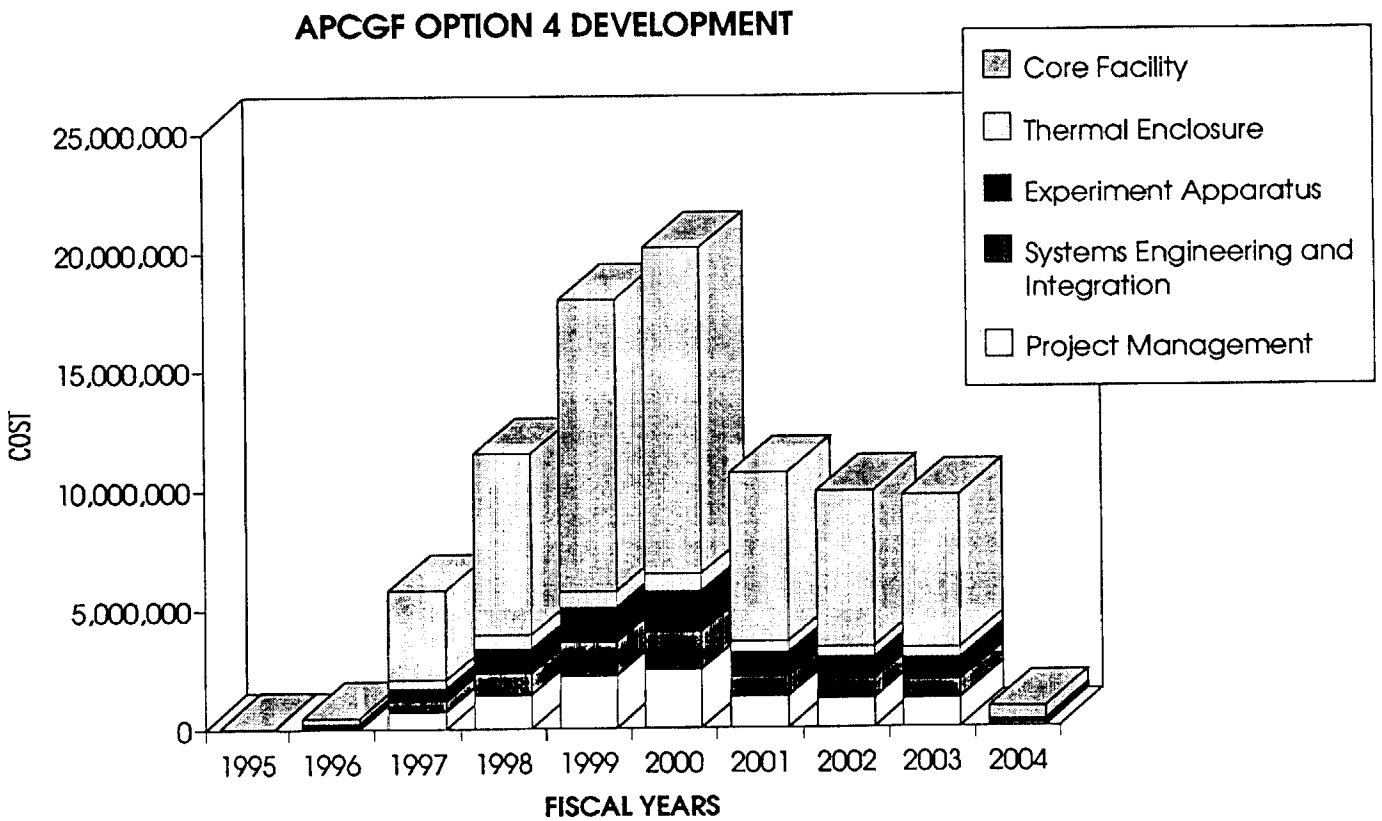
FISCAL YEARS
Core Facility
Thermal Enclosure
Experiment Apparatus
Systems Engineering and Integration
Project Management


APCGF OPTION 4 DEVELOPMENT
Core Facility
Thermal Enclosure
Experiment Apparatus
Systems Engineering and Integration
Project Management
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COST
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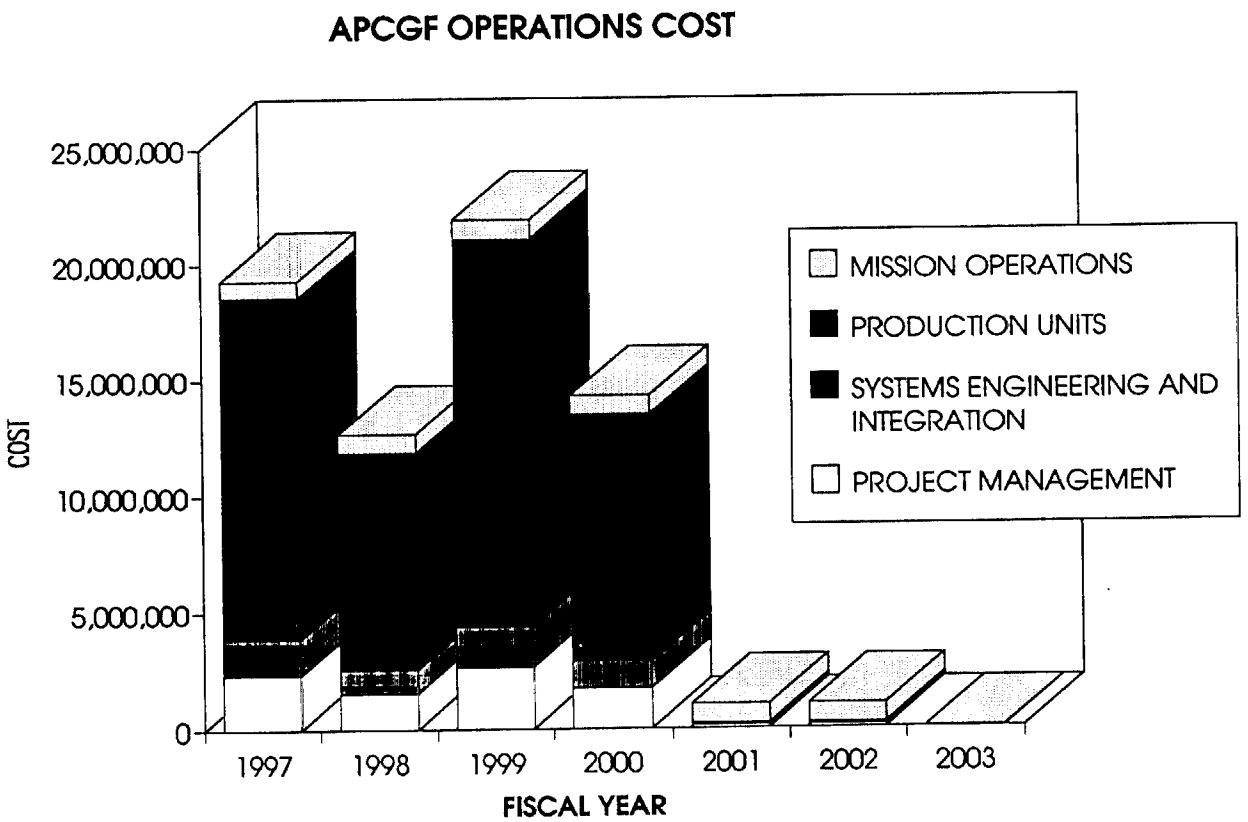
FISCAL YEARS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10,000,000
5,000,000
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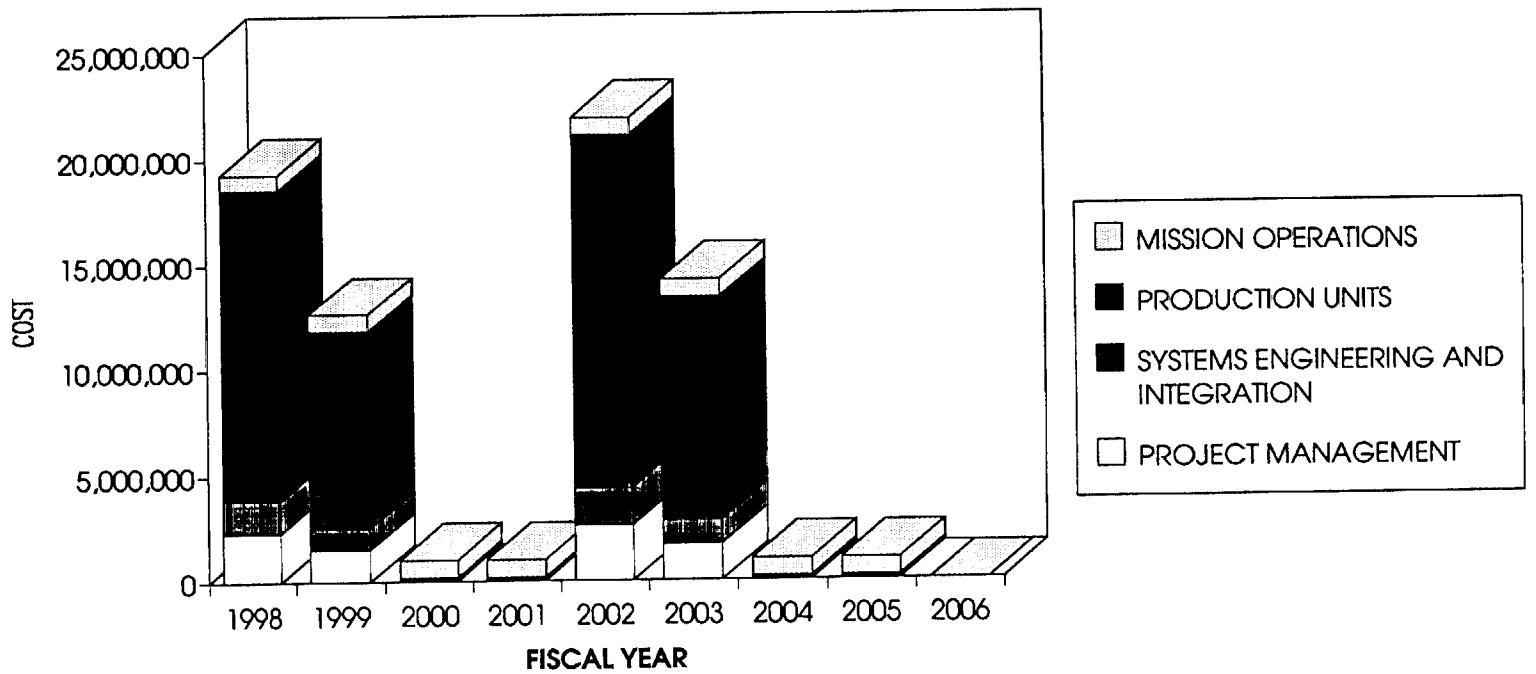
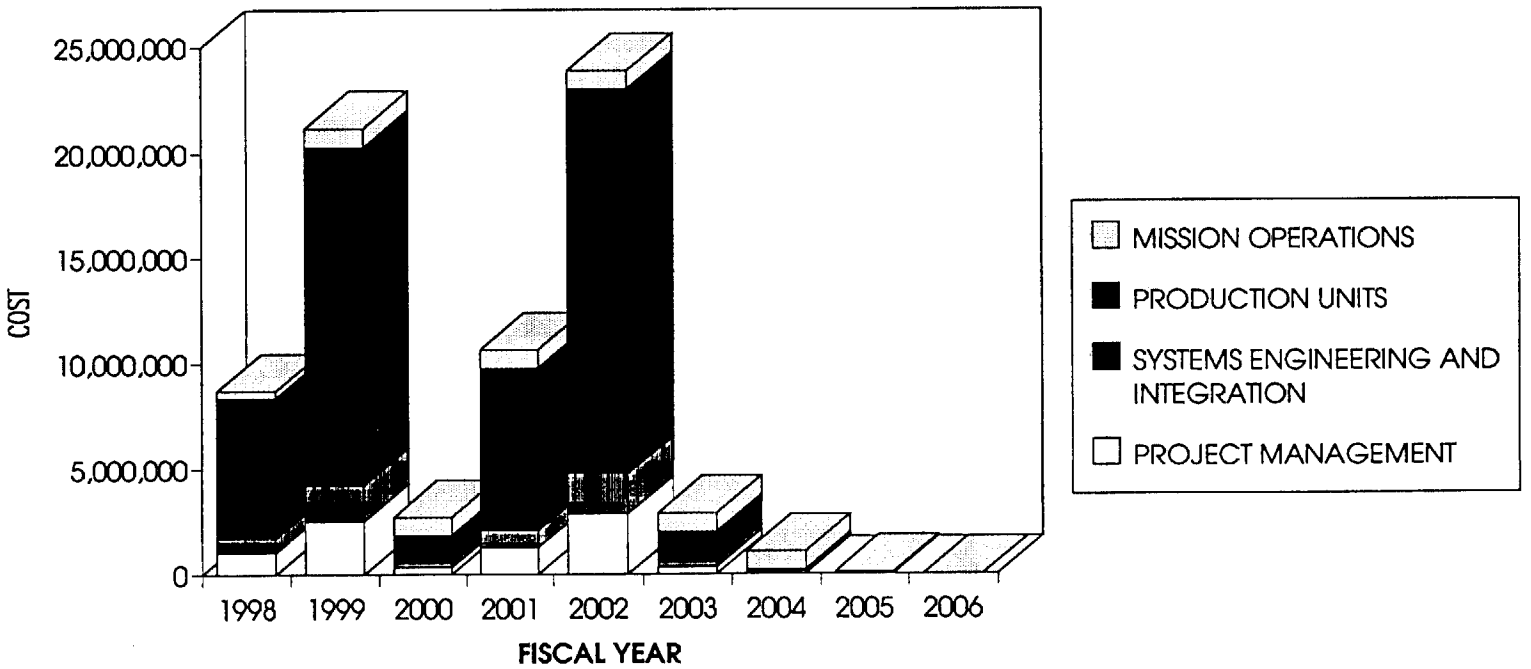
COST
1997
1998
1999
2000
2001
2002
2003
FISCAL YEAR
MISSION OPERATIONS
PRODUCTION UNITS
SYSTEMS ENGINEERING AND INTEGRATION
PROJECT MANAGEMENT

C-2

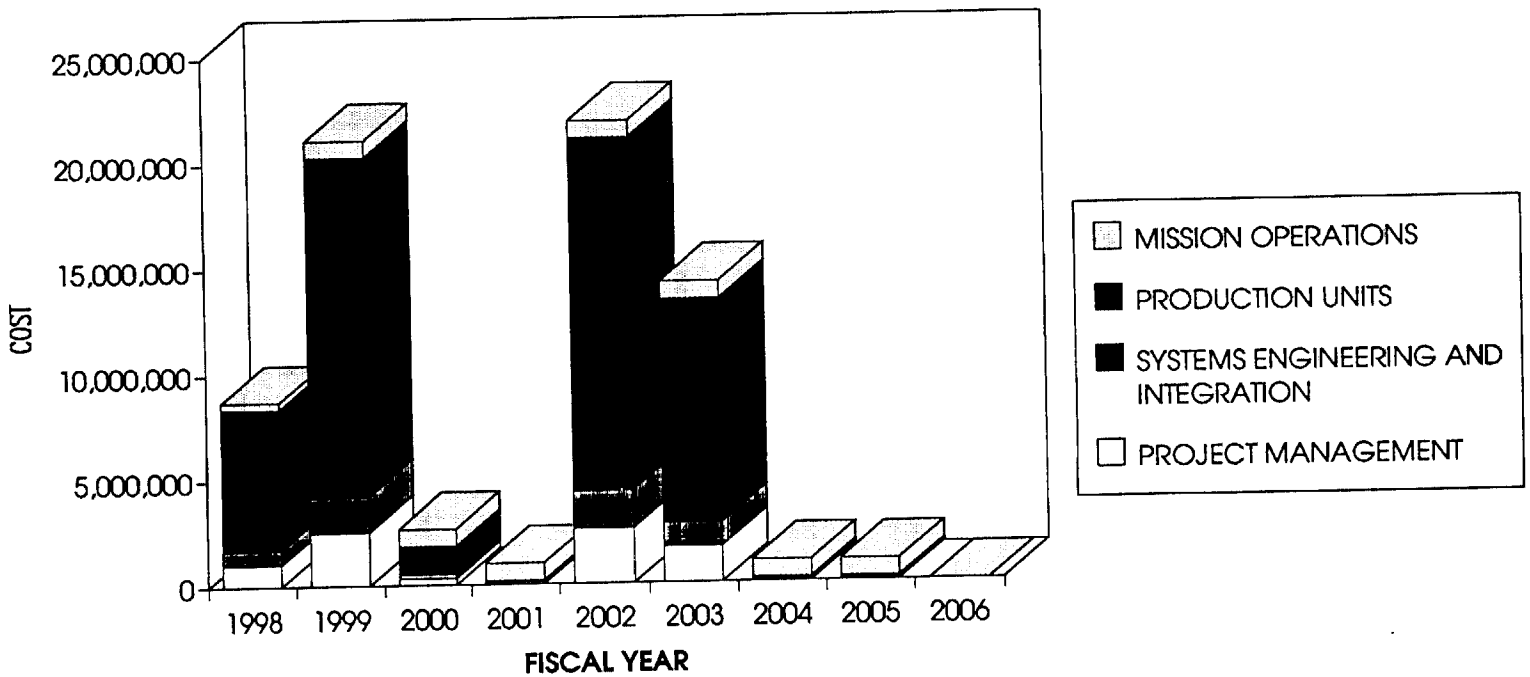
APCGF OPTION 1 OPERATIONS



APCGF OPTION 2 OPERATIONS



APCGF OPTION 3 OPERATIONS



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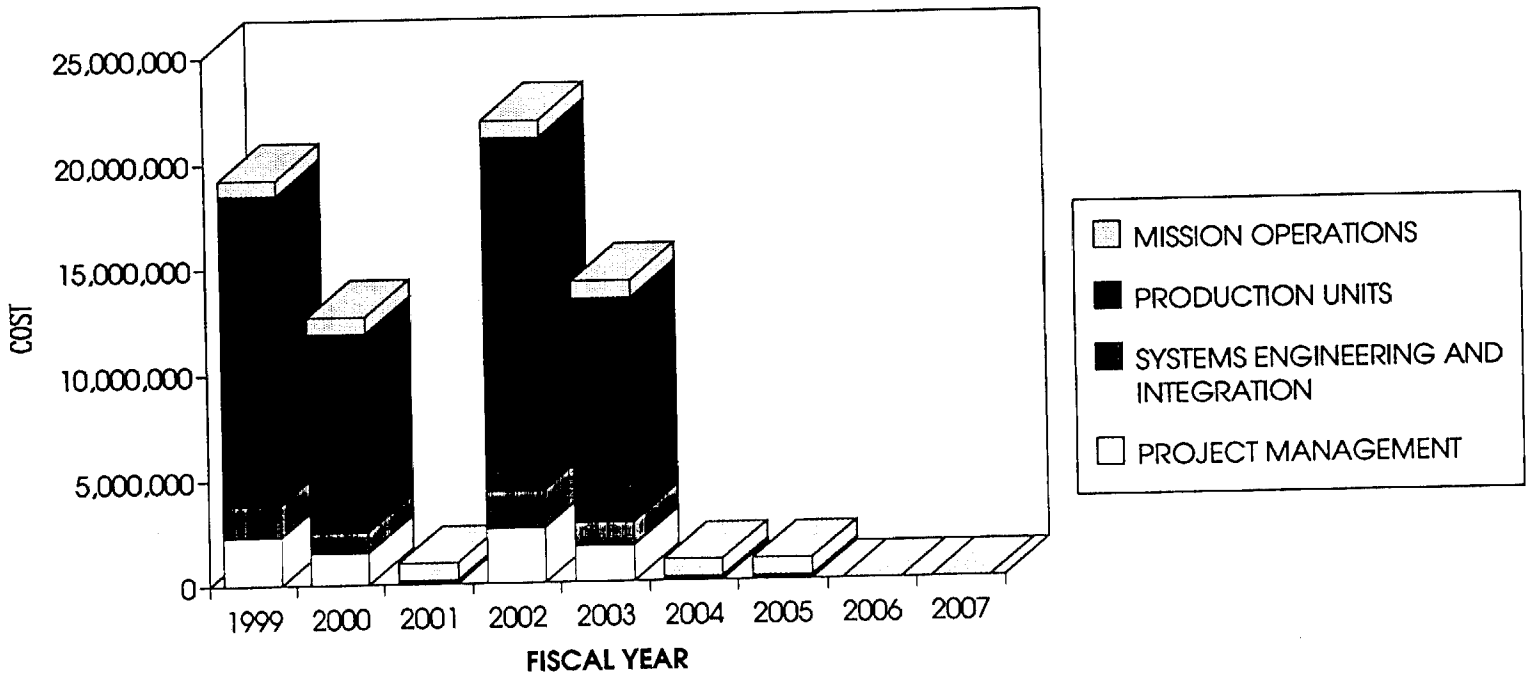

APPENDIX C

SCHEDULE CHART SUMMARIES

SCHEDULE OF MAJOR MILESTONES
BASELINE PROGRAM

	ATP	SRR	PDR	CDR	DEL	LAUNCH
EXP APP						
AO-1	1-Sep-93	14-Apr-94	15-Feb-95	25-Mar-96	13-Dec-97	1-Nov-98
AO-2	1-Apr-94	17-Oct-94	17-Jul-95	10-Jul-96	18-Jan-98	1-Nov-98
AO-3	1-Nov-94	24-Apr-95	18-Dec-95	25-Oct-96	24-Feb-98	1-Nov-98
AO-4	1-Jun-95	27-Oct-95	18-May-96	9-Feb-97	1-Apr-98	1-Nov-98
AO-5	1-Jul-95	18-Feb-96	1-Jan-97	22-Feb-98	3-Dec-99	1-Nov-00
AO-6	1-Jan-96	29-Jul-96	13-May-97	26-May-98	4-Jan-00	1-Nov-00
AO-7	1-Jul-96	5-Jan-97	21-Sep-97	25-Aug-98	4-Feb-00	1-Nov-00
AO-8	1-Jan-97	16-Jun-97	31-Jan-98	26-Nov-98	6-Mar-00	1-Nov-00
THERMAL ENC.						
ENC-1	1-Sep-93	14-Apr-94	15-Feb-95	25-Mar-96	13-Dec-97	1-Nov-98
ENC-2	1-Jul-95	18-Feb-96	1-Jan-97	22-Feb-98	3-Dec-99	1-Nov-00
FACILITY						
C-1	1-Jan-95	16-Jun-95	31-Jan-96	25-Nov-96	6-Mar-98	1-Nov-98
C-2	1-Aug-96	2-Feb-97	13-Oct-97	10-Sep-98	9-Feb-00	1-Nov-00

SCHEDULE OF MAJOR MILESTONES
OPTION 1 PROGRAM

	ATP	SRR	PDR	CDR	DEL	LAUNCH
EXP APP						
AO-1	1-Sep-94	14-Apr-95	15-Feb-96	25-Mar-97	13-Dec-98	1-Nov-99
AO-2	1-Apr-95	17-Oct-95	16-Jul-96	10-Jul-97	18-Jan-99	1-Nov-99
AO-3	1-Nov-95	23-Apr-96	17-Dec-96	25-Oct-97	24-Feb-99	1-Nov-99
AO-4	1-Jun-96	27-Oct-96	19-May-97	10-Feb-98	1-Apr-99	1-Nov-99
AO-5	1-Jul-96	16-May-97	27-Jul-98	20-Feb-00	31-Jul-02	1-Nov-03
AO-6	1-Jan-97	25-Oct-97	6-Dec-98	22-May-00	31-Aug-02	1-Nov-03
AO-7	1-Jul-97	2-Apr-98	15-Apr-99	22-Aug-00	1-Oct-02	1-Nov-03
AO-8	1-Jan-98	12-Sep-98	25-Aug-99	22-Nov-00	1-Nov-02	1-Nov-03
THERMAL ENC.						
ENC-1	1-Sep-94	14-Apr-95	15-Feb-96	25-Mar-97	13-Dec-98	1-Nov-99
ENC-2	1-Jul-96	16-May-97	27-Jul-98	20-Feb-00	31-Jul-02	1-Nov-03
FACILITY						
C-1	1-Jan-96	15-Jun-96	30-Jan-97	25-Nov-97	6-Mar-99	1-Nov-99
C-2	1-Aug-97	30-Apr-98	7-May-99	6-Sep-00	6-Oct-02	1-Nov-03

SCHEDULE OF MAJOR MILESTONES
OPTION 2 PROGRAM

	ATP	SRR	PDR	CDR	DEL	LAUNCH
EXP APP						
AO-1	1-Mar-95	12-Oct-95	14-Aug-96	22-Sep-97	13-Jun-99	1-May-00
AO-2	30-Sep-95	16-Apr-96	14-Jan-97	8-Jan-98	19-Jul-99	1-May-00
AO-3	1-May-96	22-Oct-96	17-Jun-97	25-Apr-98	25-Aug-99	1-May-00
AO-4	30-Nov-96	27-Apr-97	17-Nov-97	11-Aug-98	30-Sep-99	1-May-00
AO-5	30-Dec-96	1-Oct-97	13-Oct-98	20-Feb-00	31-Mar-02	1-May-03
AO-6	2-Jul-97	12-Mar-98	22-Feb-99	23-May-00	2-May-02	1-May-03
AO-7	30-Dec-97	19-Aug-98	2-Jul-99	22-Aug-00	2-Jun-02	1-May-03
AO-8	2-Jul-98	28-Jan-99	11-Nov-99	23-Nov-00	3-Jul-02	1-May-03
THERMAL ENC.						
ENC-1	2-Mar-95	13-Oct-95	15-Aug-96	23-Sep-97	13-Jun-99	1-May-00
ENC-2	30-Dec-96	2-Oct-97	14-Oct-98	20-Feb-00	31-Mar-02	1-May-03
FACILITY						
C-1	1-Jul-96	14-Dec-96	31-Jul-97	26-May-98	4-Sep-99	1-May-00
C-2	30-Jan-98	15-Sep-98	24-Jul-99	7-Sep-00	7-Jun-02	1-May-03

SCHEDULE OF MAJOR MILESTONES
OPTION 3 PROGRAM

	ATP	SRR	PDR	CDR	DEL	LAUNCH
EXP APP						
AO-1	1-Mar-95	12-Oct-95	14-Aug-96	22-Sep-97	13-Jun-99	1-May-00
AO-2	30-Sep-95	16-Apr-96	14-Jan-97	8-Jan-98	19-Jul-99	1-May-00
AO-3	1-May-96	22-Oct-96	17-Jun-97	25-Apr-98	25-Aug-99	1-May-00
AO-4	30-Nov-96	27-Apr-97	17-Nov-97	11-Aug-98	30-Sep-99	1-May-00
AO-5	30-Dec-96	23-Oct-97	4-Dec-98	21-May-00	31-Aug-02	1-Nov-03
AO-6	2-Jul-97	3-Apr-98	15-Apr-99	22-Aug-00	1-Oct-02	1-Nov-03
AO-7	30-Dec-97	10-Sep-98	23-Aug-99	21-Nov-00	1-Nov-02	1-Nov-03
AO-8	2-Jul-98	19-Feb-99	2-Jan-00	22-Feb-01	3-Dec-02	1-Nov-03
THERMAL ENC.						
ENC-1	2-Mar-95	13-Oct-95	15-Aug-96	23-Sep-97	13-Jun-99	1-May-00
ENC-2	30-Dec-96	24-Oct-97	5-Dec-98	22-May-00	31-Aug-02	1-Nov-03
FACILITY						
C-1	1-Jul-96	14-Dec-96	31-Jul-97	26-May-98	4-Sep-99	1-May-00
C-2	30-Jan-98	7-Oct-98	14-Sep-99	7-Dec-00	6-Nov-02	1-Nov-03

SCHEDULE OF MAJOR MILESTONES
OPTION 4 PROGRAM

	ATP	SRR	PDR	CDR	DEL	LAUNCH
EXP APP						
AO-1	1-Sep-95	13-Apr-96	14-Feb-97	25-Mar-98	14-Dec-99	1-Nov-00
AO-2	1-Apr-96	17-Oct-96	17-Jul-97	11-Jul-98	19-Jan-00	1-Nov-00
AO-3	1-Nov-96	24-Apr-97	18-Dec-97	26-Oct-98	25-Feb-00	1-Nov-00
AO-4	1-Apr-97	4-Sep-97	5-Apr-98	10-Jan-99	22-Mar-00	1-Nov-00
AO-5	1-Jul-97	2-Apr-98	15-Apr-99	22-Aug-00	1-Oct-02	1-Nov-03
AO-6	1-Jan-98	12-Sep-98	25-Aug-99	22-Nov-00	1-Nov-02	1-Nov-03
AO-7	1-Jul-98	18-Feb-99	2-Jan-00	22-Feb-01	2-Dec-02	1-Nov-03
AO-8	1-Jan-99	30-Jul-99	13-May-00	25-May-01	3-Jan-03	1-Nov-03
THERMAL ENC.						
ENC-1	1-Sep-95	13-Apr-96	14-Feb-97	25-Mar-98	14-Dec-99	1-Nov-00
ENC-2	1-Jul-97	2-Apr-98	15-Apr-99	22-Aug-00	1-Oct-02	1-Nov-03
FACILITY						
C-1	1-Jan-97	16-Jun-97	31-Jan-98	26-Nov-98	6-Mar-00	1-Nov-00
C-2	1-Aug-98	17-Mar-99	24-Jan-00	9-Mar-01	8-Dec-02	1-Nov-03

APPENDIX D

WORK BREAKDOWN STRUCTURE

	WBS TITLE
1.0	APCG PROGRAMMATIC STUDY
2.0	ADVANCED PROTEIN CRYSTAL GROWTH
2.1	Development
2.1.1	Project Management
2.1.2	Science Support
2.1.3	Systems Engineering and Integration
2.1.4	Design, Development, Manufacturing & Test
2.1.4.1	Experiment Apparatus
2.1.4.1.1	Experiment Apparatus 1
2.1.4.1.2	Experiment Apparatus 2
2.1.4.1.3	Experiment Apparatus 3
2.2	Integration
2.2.1	KSC Launch Preparation
2.2.2	KSC Landing Deactivation
2.3	Operations
2.3.1	Flight Operations
2.3.2	Ground Operations
3.0	ADVANCED PROTEIN CRYSTAL GROWTH TRANSITION
3.1	Development
3.1.1	Project Management
3.1.2	Science Support

3.1.3	Systems Engineering and Integration
3.1.4	Design, Development, Manufacturing & Test
3.1.4.1	Thermal Enclosure Modifications
3.1.4.1.1	Refrigerator Incubator Module (RIM)
3.1.4.1.2	Thermal Enclosure System (TES)
3.1.4.1.3	Modular Stowage Locker (MSL)
3.1.4.1.3	Mid-deck Experiment Apparatus Container (EAC)
3.1.4.2	Support Equipment
3.1.4.2.1	Ground Support Equipment
3.1.4.2.2	Flight Support Equipment
3.2	Integration
3.2.1	KSC Launch Preparation
3.2.2	KSC Landing Deactivation
3.3	Operations
3.3.1	Flight Operations
3.3.2	Ground Operations
4.0	ADVANCED PROTEIN CRYSTAL GROWTH FACILITY
4.1	Development
4.1.1	Project Management
4.1.2	Science Support
4.1.3	Systems Engineering and Integration
4.1.4	Design, Development, Manufacturing & Test
4.1.4.1	Experiment Apparatus
4.1.4.1.1	Experiment Apparatus 1

4.1.4.1.2	Experiment Apparatus 2
4.1.4.1.3	Experiment Apparatus 3
4.1.4.1.4	Experiment Apparatus 4
4.1.4.1.5	Experiment Apparatus 5
4.1.4.1.6	Experiment Apparatus 6
4.1.4.1.7	Experiment Apparatus 7
4.1.4.1.8	Experiment Apparatus 8
4.1.4.2	Thermal Enclosure
4.1.4.2.1	Thermal Enclosure 1
4.1.4.2.2	Thermal Enclosure 2
4.1.4.3	Core Facility
4.1.4.3.1	Rack 1
4.1.4.3.2	Rack 2
4.2	Integration
4.2.1	KSC Launch Preparation
4.2.2	KSC Landing and Deactivation
4.3	Operations
4.3.1	Flight Operation
4.3.2	Ground Operations

DESCRIPTION OF WBS ELEMENTS

2.1 Development

This element includes the Project Management, Science Support, and Systems Engineering activities needed for project direction and to assure overall project performance. It also includes the effort to design, manufacture,

and test the development of experiment apparatus, supporting equipment, and tooling for Space Shuttle crystal growth experiment mid-deck flights.

2.1.1 Project Management

This element provides the scientific, technical, and administrative direction to assure project objectives are achieved within performance goals, schedule, and cost.

2.1.2 Science Support

This element contains scientific support to the project for management, systems requirements, definition, design, and for ground and flight operations.

2.1.3 Systems Engineering

This WBS element includes all labor, materials, and other resources necessary to perform all the systems engineering functions required to assure overall system performance. Activities include mission requirements and analysis, system analysis and requirements, system configurations, verification requirements, operations support requirements, product assurance, and logistics requirements.

2.1.4 Design, Development, Manufacturing & Test

This WBS element includes all labor, materials, and other resources required to perform
the analysis, design, design trades, design verification, development, and development testing activities for the apparatus in accordance with the EI Specifications. Also included is the preparation of design drawings, parts lists, and analytical modeling. The development of all subsystem test hardware, including mock-ups, breadboards, brassboards, engineering models, and test specimens is included.

2.1.4.1 Experiment Apparatus 1

This element provides for the design and development of an experiment apparatus selected from the August 23, 1991 Microgravity Biotechnology NASA Research Announcement that is to be developed under the direction of the PI.

2.1.4.2 Experiment Apparatus 2

This element provides for the design and development of an experiment apparatus selected from the August 23, 1991 Microgravity Biotechnology NASA Research Announcement that is to be developed under the direction of the PI.

2.1.4.3 Experiment Apparatus 3

This element provides for the design and development of an experiment apparatus selected from the August 23, 1991 Microgravity Biotechnology NASA Research Announcement that is to be developed by NASA.

2.2 Integration

This element includes the effort required to support the KSC pre-flight integration and post-launch activity for flight "safing" of hardware, removal from the orbiter, inspection, and checkout preparation for shipment, analysis , and documentation.

2.2.1 KSC Launch Preparation

This element includes effort required to support the KSC launch operations activity. This includes the effort to plan,organize, and execute pre-flight integration, GSE, checkout and handling of the flight experiment and scientific samples.

2.2.2 KSC Landing and Deactivation

This element includes post-launch activity for flight "safing" of the experiment, removal from the Orbiter, inspection and checkout, preparation for shipment, and analysis and documentation.

2.3 Operations

Provide effort to support the mission operation activity in the areas of flight planning, training, simulation, flight operations, post-flight analysis, refurbishment, inspection and checkout, and shipment to KSC for reflight.

2.3.1 Flight Operation

Provide effort to support the mission operations activity in the areas of flight planning, flight operations, and post-flight analysis. Develop the flight sequencing of events to complete the prescribed mission and contingency planning. Develop documentation and plans to be supplied for training and simulation. Develop the Payload Operations Control Plan.

2.3.2 Ground Experiment Operations

This element includes the effort, services, materials, and support required to produce ground control experiment samples during ground and flight operation and testing.

3.0 ADVANCED PROTEIN CRYSTAL GROWTH TRANSITION

3.1 Development

This element includes the Project Management, Science Support, and Systems Engineering activities needed for project direction and to assure overall project performance. It also includes the effort to design, manufacture, and test modifications to the experiment thermal enclosures and other experiment ground and flight hardware/software necessary for operations on the early Space Station Freedom.

3.1.1 Project Management

This element provides the scientific, technical, and administrative direction to assure project objectives are achieved within performance goals, schedule, and cost.

3.1.2 Science Support

This element contains scientific support to the project for management, systems requirements, definition, design, and for ground and flight operations.

3.1.3 Systems Engineering

This WBS element includes all labor, materials, and other resources necessary to perform all the systems engineering functions required to assure overall system performance. Activities include mission requirements and analysis, system analysis and requirements, system configurations, verification requirements, operations support requirements, product assurance, and logistics requirements.

3.1.4 Design, Development, Manufacturing & Test

This WBS element includes all labor, materials, and other resources required to perform the analysis, design, design trades, design verification, development, and development testing activities needed to change the APCG experiments for flight on the early Space Station Freedom. The development of all subsystem test hardware, including mock-ups, breadboards, brassboards, engineering models, and test specimens is included.

3.1.4.1 Thermal Enclosure Systems Modifications

This element provides for design, development, manufacturing, and test effort needed for modifications to experiment thermal enclosures.

3.1.4.1.1 Refrigerator Incubator Module (RIM)

This element provides for design, development, manufacturing, and test effort needed for modifications to the Refrigerator Incubator Module.

3.1.4.1.2 Thermal Enclosure System (TES)

This element provides for design, development, manufacturing, and test effort needed for modifications to the Thermal Enclosure System.

3.1.4.1.3 Modular Stowage Locker (MSL)

This element provides for design, development, manufacturing, and test effort needed for modifications to the Modular Stowage Locker.

3.1.4.1.4 Mid-deck Experiment Apparatus Container (EAC)

3.1.4.2 Support Equipment

This element provides for design, development, manufacturing, and test effort needed for modifications to the ground and flight support equipment.

3.1.4.2.1 Ground Support Equipment

This element provides for design, development, manufacturing, and test effort needed for modifications to the ground support equipment.

3.1.4.2.2 Flight Support Equipment

This element provides for design development, manufacturing, and test effort needed for modifications to the flight support equipment.

3.2 Integration

This element includes the effort required to support the KSC pre-flight integration and post-launch activity for flight "safing" of hardware, removal from the orbiter, inspection, and checkout preparation for shipment, analysis, and documentations.

3.2.1 KSC Launch Preparation

This element includes effort required to support the KSC launch operations activity. This includes the effort to plan, organize, and execute pre-flight integration, GSE, checkout, and handling of the flight experiment and scientific samples.

3.2.2 KSC Landing and Deactivation

This element includes post-launch activity for flight "safing" of the experiment, removal from the Orbiter, inspection and checkout, preparation for shipment, and analysis and documentation.

3.3 Operations

Provide effort to support the mission operation activity in the areas of flight planning, training, simulation, flight operations, post-flight analysis, refurbishment, inspection and checkout, and shipment to KSC for reflight.

3.3.1 Flight Operation

Provide effort to support the mission operations activity in the areas of flight planning, flight operations, and post-flight analysis. Develop the flight sequencing of events to complete the prescribed mission and contingency planning. Develop documentation and plans to be supplied for training and simulation. Develop the Payload Operations Control Plan.

3.3.2 Ground Experiment Operations

This element includes the effort, services, materials, and support required to produce ground control experiment samples during ground and flight operation and testing.

4.0 ADVANCED PROTEIN CRYSTAL GROWTH FACILITY

4.1 Development

This element includes the Project Management, Science Support, and Systems Engineering activities needed for project direction and to assure overall project performance. It also includes the effort to design, manufacture, and test the development of experiment apparatus, supporting equipment, and tooling for Space Station Freedom manned flights.

4.1.1 Project Management

This element provides the scientific, technical, and administrative direction to assure project objectives are achieved within performance goals, schedule, and cost.

4.1.2 Science Support

This element contains scientific support to the project for management, systems requirements, definition, design, and for ground and flight operations.

4.1.3 Systems Engineering

This WBS element includes all labor, materials, and other resources necessary to perform all the systems engineering functions required to assure overall system performance. Activities include mission requirements and analysis, system analysis and requirements, system configurations, verification requirements, operations support requirements, product assurance, and logistics requirements.

4.1.4 Design, Development, Manufacturing & Test

This WBS element includes all labor, materials, and other resources required to perform
the analysis, design, design trades, design verification, development, and development testing activities for the apparatus in accordance with the EI Specifications. Also included is the preparation of design drawings, parts lists, and analytical modeling. The development of all subsystem test hardware, including mock-ups, breadboards, brassboards, engineering models, and test specimens is included.

4.1.4.1 Experiment Apparatus

This element provides for the design and development of experiment apparatus selected from the Microgravity Biotechnology NASA Announcement of Opportunity.

4.1.4.1.1 Experiment Apparatus 1

This element provides for the design, development, manufacturing, and test of an experiment apparatus selected from the 1992 Microgravity Biotechnology NASA Announcement of Opportunity that is to be developed under the direction of the PI.

4.1.4.1.2 Experiment Apparatus 2

This element provides for the design, development, manufacturing, and test of an experiment apparatus selected from the 1992 Microgravity Biotechnology NASA Announcement of Opportunity that is to be developed under the direction of the PI.

4.1.4.1.3 Experiment Apparatus 3

This element provides for the design, development,manufacturing, and test of an experiment apparatus selected from the 1992 Microgravity Biotechnology NASA Announcement of Opportunity that is to be developed by NASA.

4.1.4.1.4 Experiment Apparatus 4

This element provides for the design, development manufacturing, and test of an experiment apparatus selected from the 1992 Microgravity Biotechnology NASA Announcement of Opportunity that is to be developed by NASA.

4.1.4.1.5 Experiment Apparatus 5

This element provides for the design, development, manufacturing, and test of an experiment apparatus selected from the Phase 2 Microgravity Biotechnology NASA Announcement of Opportunity that is to be developed under the direction of the PI.

4.1.4.1.6 Experiment Apparatus 6

This element provides for the design, development, manufacturing, and test of an experiment apparatus selected from the Phase 2 Microgravity Biotechnology NASA Announcement of that is to be developed under the direction of the PI.

4.1.4.1.7 Experiment Apparatus 7

This element provides for the design, development, manufacturing, and test of an experiment apparatus selected from the Phase 2 Microgravity Biotechnology NASA Announcement of Opportunity that is to be developed by NASA.

4.1.4.1.8 Experiment Apparatus 8

This element provides for the design, development, manufacturing, and test of an experiment apparatus selected from the Phase 2 Microgravity Biotechnology NASA Announcement of Opportunity that is to be developed by NASA.

4.1.4.2 Thermal Enclosure

This element provides for the design, development, manufacturing, and test of thermal enclosure systems selected from the 1992 Microgravity Biotechnology NASA Announcement of Opportunity.

4.1.4.2.1 Thermal Enclosure 1

This element provides for the design, development, manufacturing, and test of an experiment enclosure selected from the Phase 2 Microgravity Biotechnology NASA Announcement of Opportunity that is to be developed under the direction of the PI.

4.1.4.2.2 Thermal Enclosure 2

This element provides for the design, development, manufacturing, and test of an experiment enclosure selected from the Phase 2 Microgravity Biotechnology NASA Announcement of Opportunity that is to be developed under the direction of the PI.

4.1.4.3 Core Facility

This element provides for the design, development, manufacturing, and test of core facilities selected from the Microgravity Biotechnology NASA Announcements of Opportunity.

4.1.4.3.1 Rack 1

This element provides for the design, development, manufacturing, and test of rack 1 selected from the 1992 Microgravity Biotechnology NASA Announcement of Opportunity.

4.1.4.3.2 Rack 2

This element provides for the design, development, manufacturing, and test of rack 2 selected from the Phase 2 NASA Announcement of Opportunity.

4.2 Integration

This element includes the effort required to support the KSC pre-flight integration and post-launch activity for flight "safing" of hardware, removal from the orbiter, inspection, and checkout preparation for shipment, analysis, and documentations.

4.2.1 KSC Launch Preparation

This element includes effort required to support the KSC launch operations activity. This includes the effort to plan, organize, and execute pre-flight integration, GSE, checkout, and handling of the flight experiment and scientific samples.

4.2.2 KSC Landing and Deactivation

This element includes post-launch activity for flight "safing" of the experiment, removal from the Orbiter, inspection and checkout, preparation for shipment, and analysis and documentation.

4.3 Operations

Provide effort to support the mission operation activity in the areas of flight planning, training, simulation, flight operations, post-flight analysis, refurbishment, inspection and checkout, and shipment to KSC for reflight.

4.3.1 Flight Operation

Provide effort to support the mission operations activity in the areas of flight planning, flight operations, and post-flight analysis. Develop the flight sequencing of events to complete the prescribed mission and contingency planning. Develop documentation and plans to be supplied for training and simulation. Develop the Payload Operations Control Plan.

4.3.2 Ground Experiment Operations

This element includes the effort, services, materials, and support required to produce ground control experiment samples during ground and flight operation and testing.

APPENDIX E

COMPUTER PROGRAM OPERATING PROCEDURE

COMPUTER PROGRAM PROCEDURE

Procedure for use of the Advanced Protein Crystal Growth Facility (APCGF) Computer Cost Program.

The program uses Excel 3.0 for Windows for use on IBM compatible computers.

The program has one Workspace File, APCG.XLW, which includes all files needed for Development Cost and Operations cost. A list of all files is included on the last page of this document.

All of the files on the disk should be copied into a directory of the user's choice.

The procedure is as follows:

Start Excel

Open APCG.XLW from the File Menu

Opens all needed files

Follow the directions that are given on the screen.

COMPUTER PROGRAM NOTES

Both the development and operations costs are calculated. Development costs may be input by the user. The operations costs are based on the development costs. The production cost used in operations is a fixed percentage of the development cost of the element (apparatus, facility or enclosure).

When using the program, avoid saving any of the original files. When you are ready to stop exit without saving any changes. Saving over the original files may result in incorrect results. If this should occur,simply re-copy the original files from the disk.

Any of the files created by the operation of the program may be saved into any location desired and will have no effect on on the future operation of the original files.

APPENDIX F

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